FORESTRY

THE JOURNAL OF THE SOCIETY OF FORESTERS OF GREAT BRITAIN

Edited by C. W. SCOTT

VOLUME XXIII : NUMBER 1

1949

Price
Seven Shillings and Sixpence

Published by the
OXFORD UNIVERSITY PRESS
LONDON: GEOFFREY CUMBERLEGE
AMEN HOUSE, E.C.4
1949

31 JAN. 1950

A NOTE ON THE MOVEMENT OF TREE CLASSES

By W. H. GUILLEBAUD and F. C. HUMMEL

(*Forestry Commission*)

EVEN in very uniform stands of a single species and age the individual trees differ from one another in vigour and height, and it is possible to distinguish between several canopy or tree classes. In the sample plots of the Forestry Commission the trees are divided into four main classes—dominants, co-dominants, sub-dominants, and suppressed trees. There is a fifth class for dead and dying trees and a sixth class for diseased trees (3). In practice class 6 has rarely been used because it is more satisfactory to put a diseased tree into its proper canopy class and add a symbol, e.g. *K* for canker, to denote the presence of disease.

The object of the investigation which is described in this paper was to find out how the various tree classes are represented in pure even-aged crops at different ages and under different thinning treatments, and to what extent individual trees tend to maintain or change their relative position in the canopy during the life of a stand.

The movement of tree classes is not only of academic interest, but it bears also on thinning policy and practice because the art of marking thinnings depends at least in part on judging correctly how the removal of trees is likely to affect the future position in the canopy of those that are left standing.

Six pairs of plots were chosen for study, which had been thinned and re-measured 4–8 times, over a total period of 15–25 years. Norway spruce (*Picea abies* Karst.), Sitka spruce (*Picea sitchensis* Carr.), Scots pine (*Pinus sylvestris* L.), and Japanese larch (*Larix leptolepis* Gord.) are each represented by one pair of plots, and Douglas fir (*Pseudotsuga taxifolia* Brit.) by two. At the time of the first measurement the two plots forming each pair were closely comparable with one another in origin, age, site, height, and number of stems, but they were then subjected to different thinning treatments, the one to a light low thinning (B grade) and the other to a moderate (C grade) or heavy (D grade) low thinning. Differences that have developed between the two plots of each pair since the first measurement can thus safely be attributed to the contrasting effects of the thinning treatments. The trees were classified at each re-measurement so that it was not difficult to trace the fate of all the trees in a class; but as there were up to 1,200 trees in a ½-acre plot, the computational work involved was very considerable. This explains why this investigation was restricted to six pairs of plots, and it may also explain the paucity of literature on the subject. Although substantial data must have accumulated in the numerous sample plots in Germany and other European countries where similar classifications have been in use for over half a century, only three articles (1, 3, 5) were found which deal with the movement of tree classes. These articles are discussed briefly towards the end of this paper.

While the two plots within each series were closely comparable with one another, at the outset there were considerable differences between the series, in age, stocking, and past thinning treatments, as is evident from an inspection of Table I. Thus one pair of Douglas fir plots started with 2,800 to 3,000 stems per acre, the Sitka spruce and Japanese larch plots with 2,300 to 2,600, the Norway spruce with 1,500 to 1,800, and the Scots pine and the second pair of Douglas fir plots with only 1,200 to 1,300 stems per acre. These last two pairs of plots were 35 years and 21 years old, respectively, and had been thinned previously, while the other four pairs of plots were between 15 and 19 years old and had not been thinned before. These initial disparities obscure the differences that may exist between the various species in the distribution and movement of tree classes; and the precision of the data may be further reduced by the presence of 'border-line' trees, which one observer might put into one class and another observer into the next higher or lower class, as the case may be. These factors invalidate any attempt at comparisons between species, but not between the two plots in each series. They render all the more significant the broad trends which all the examined plots were found to have in common, and it is on these trends mainly that attention will be focused in the discussion which follows.

The results are summarized in Tables I to III, which speak for themselves, and in Figs. 1 to 6, which may require some explanation. The number of stems per acre, before and after each thinning, has been plotted over age, so that the vertical distance between the horizontal axis of the graph and the first line gives the number of dominants, the interval between that line and the next the number of co-dominants, and the interval above that the number of sub-dominants, suppressed, dead, and dying trees. The total vertical distance between the horizontal axis of the graph and the uppermost horizontal line thus gives the total growing-stock per acre at a given age. The ages inserted in the graphs are those at which thinnings were carried out, and the vertical drops at these points represent the number of trees in each class that were cut out.

The total number of trees between two thinnings normally remains constant, and in such case the line denoting the upper limit of the sub-dominants is horizontal. When this line dips it means that wind-falls or other accidents have reduced the total growing stock. When the vertical distance for any one class remains the same during a period, there have been either no movements of trees between that class and the adjoining classes, or recruitment and losses have been equal. Similarly, increasing intervals denote an excess of recruitment over losses, and decreasing intervals the opposite. In the four pairs of plots that were established in 1923 or before, dominants and co-dominants have not been separated. They are shown together during the first period because at that time a slightly different tree classification was in use, which did not distinguish clearly between these two upper classes. Details of this old classification are given in *Outlines for Permanent Sample Plot Investigations* (2).

In nearly all the plots dominants show a net loss and sub-dominants a net gain during most periods, indicating a general downward trend in the movement of tree classes. The only notable exceptions to this occur in the first period, which

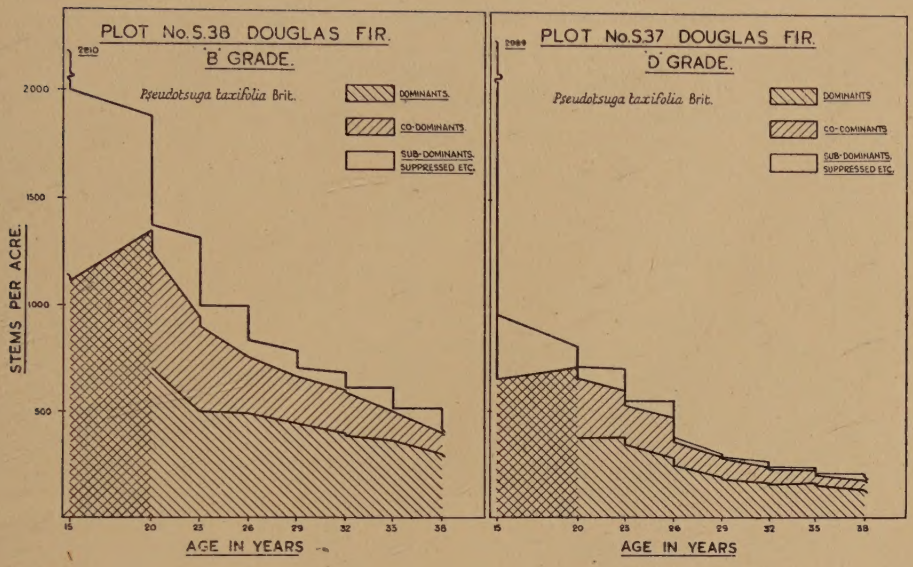
PLOT No.S.38 DOUGLAS FIR.
'B' GRADE.
Pseudotsuga taxifolia Brit.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
STEMS PER ACRE.
2000
1500
1000
500
15
20
23
26
29
32
35
38
AGE IN YEARS
PLOT No.S.37 DOUGLAS FIR.
'D' GRADE.
Pseudotsuga taxifolia Brit.
DOMINANTS
CO-DOMINANTS
SUB-DOMINANTS. SUPPRESSED ETC.
AGE IN YEARS

FIG. 1

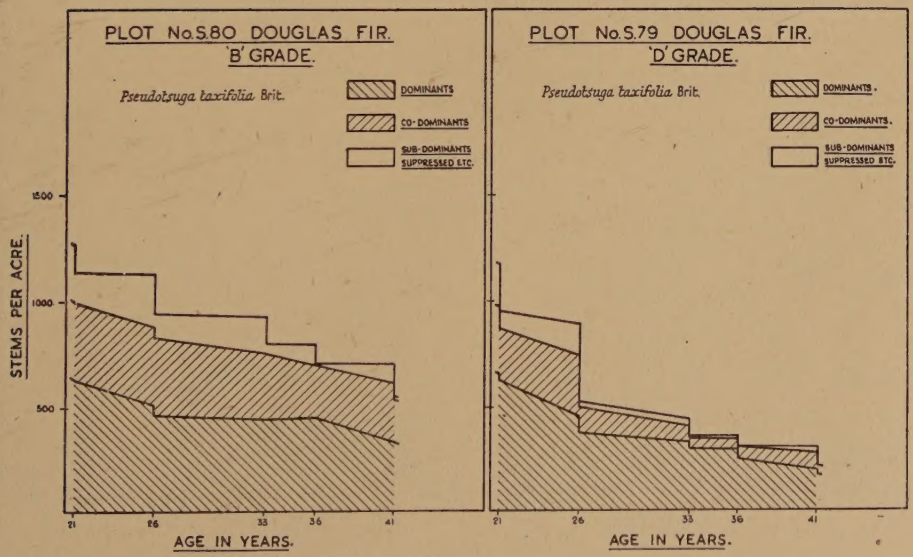
PLOT No.S.80 DOUGLAS FIR.
'B' GRADE.
Pseudotsuga taxifolia Brit.
DOMINANTS
CO-DOMINANTS
SUB-DOMINANTS SUPPRESSED ETC.
STEMS PER ACRE.
1500
1000
500
21
26
33
36
41
AGE IN YEARS.
PLOT No.S.79 DOUGLAS FIR.
'D' GRADE.
Pseudotsuga taxifolia Brit.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS SUPPRESSED ETC.
AGE IN YEARS.

FIG. 2

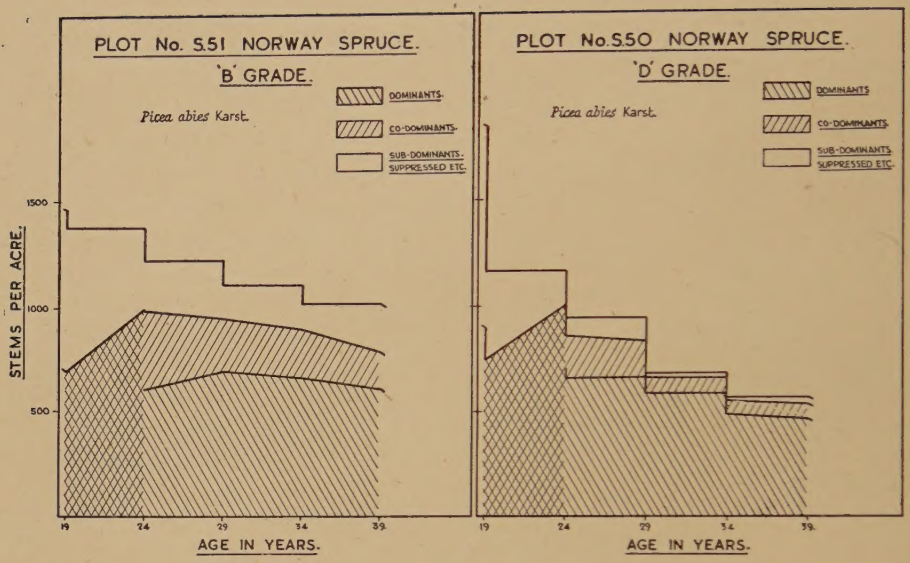
PLOT No. S.51 NORWAY SPRUCE.
'B' GRADE.
Picea abies Karst.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
PLOT No.S.50 NORWAY SPRUCE.
'D' GRADE.
Picea abies Karst.
DOMINANTS
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
STEMS PER ACRE.
1500
1000
500
19
24
29
34
39.
AGE IN YEARS.
AGE IN YEARS.

FIG. 3

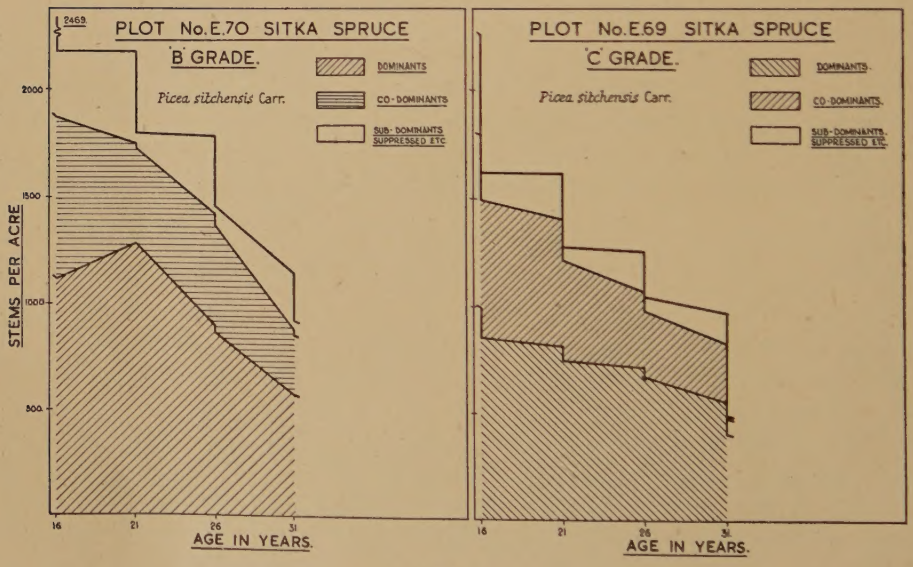
2469
PLOT No.E.70 SITKA SPRUCE
'B' GRADE.
Picea sitchensis Carr.
DOMINANTS
CO-DOMINANTS
SUB-DOMINANTS SUPPRESSED ETC.
PLOT No.E.69 SITKA SPRUCE
'C' GRADE.
Picea sitchensis Carr.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
STEMS PER ACRE
2000
1500
1000
500
16
21
26
31
AGE IN YEARS.
AGE IN YEARS.

FIG. 4

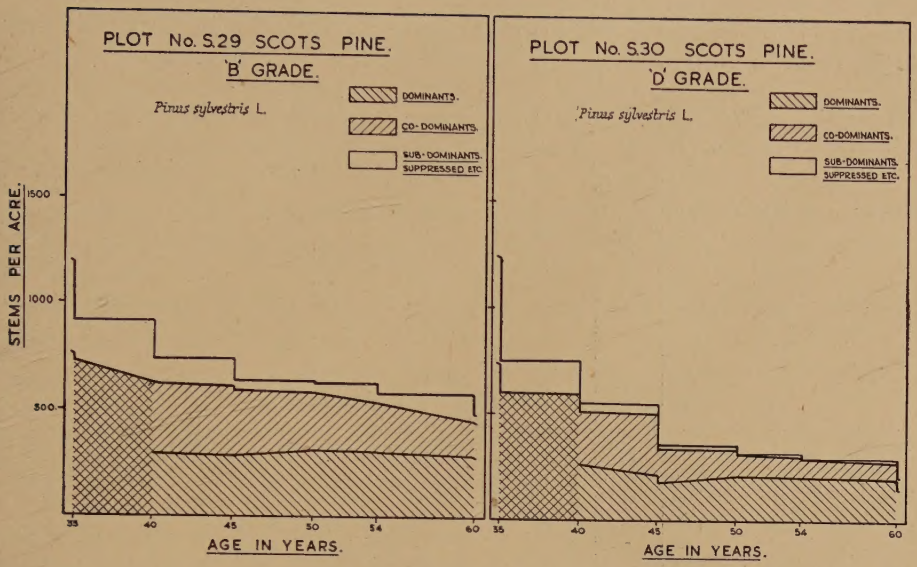
PLOT No. S.29 SCOTS PINE.
'B' GRADE.
Pinus sylvestris L.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
STEMS PER ACRE.
1500
1000
500
35
40
45
50
54
60
AGE IN YEARS.
PLOT No. S.30 SCOTS PINE.
'D' GRADE.
Pinus sylvestris L.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
35
40
45
50
54
60
AGE IN YEARS.

FIG. 5

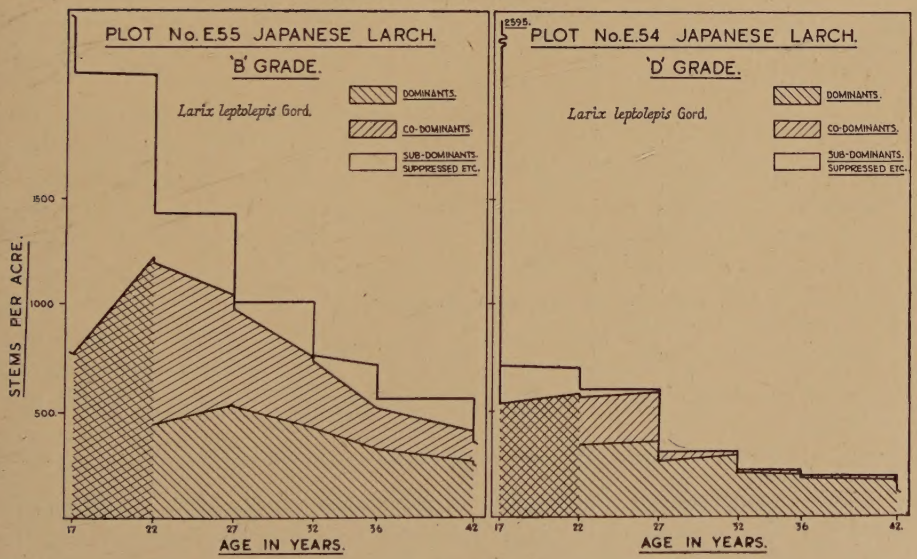
PLOT No. E.55 JAPANESE LARCH.
'B' GRADE.
Larix leptolepis Gord.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
STEMS PER ACRE.
1500
1000
500
17
22
27
32
36
42
AGE IN YEARS.
2595.
PLOT No. E.54 JAPANESE LARCH.
'D' GRADE.
Larix leptolepis Gord.
DOMINANTS.
CO-DOMINANTS.
SUB-DOMINANTS. SUPPRESSED ETC.
17
22
27
32
36
42.
AGE IN YEARS.

FIG. 6

suggests that they may be due to the change in the method of classification, rather than to a real upward movement from the sub-dominant class.

TABLE I. *Number and percentage of trees in each tree class at beginning and end of period*

Species	*Plot no.*	*Thinning grade*	*Age*	*Number and, in brackets, percentage of trees per acre.*			
				Dominants	*Co-dominants*	*Other classes*	*Total (100 %)*
Douglas fir (*Pseudotsuga taxifolia* Brit.)	S.38	B	15	1,130 (40)		1,680 (60)	2,810
			38	299 (68)	104 (24)	36 (8)	439
	S.37	D	15	1,057 (35)		1,932 (65)	2,989
			38	132 (68)	51 (27)	10 (5)	193
Douglas fir	S.80	B	21	629 (50)	361 (29)	272 (21)	1,262
			41	340 (62)	201 (36)	10 (2)	551
	S.79	D	21	653 (56)	303 (26)	209 (18)	1,165
			41	175 (83)	37 (17)	..	212
Norway spruce (*Picea abies* Karst.)	E.51	B	19	691 (47)		767 (53)	1,460
			39	607 (60)	179 (18)	225 (22)	1,011
	E.50	D	19	898 (49)		944 (51)	1,842
			39	462 (83)	68 (12)	30 (5)	560
Sitka spruce (*Picea sitchensis* Carr.)	E.70	B	16	1,097 (44)	767 (31)	632 (25)	2,496
			31	746 (62)	379 (32)	75 (6)	1,200
	E.69	C	16	1,129 (45)	842 (34)	510 (21)	2,481
			31	401 (82)	74 (15)	15 (3)	490
Scots pine (*Pinus sylvestris* L.)	S.29	B	35	757 (63)		437 (37)	1,194
			60	293 (59)	163 (33)	38 (8)	494
	S.30	D	35	744 (60)		500 (40)	1,244
			60	168 (81)	40 (19)	..	208
Japanese larch (*Larix leptolepis* Gord.)	E.55	B	17	761 (33)		1,579 (67)	2,340
			42	255 (68)	101 (27)	21 (5)	377
	E.54	D	17	951 (37)		1,644 (63)	2,595
			42	140 (98)	3 (2)	..	143

Table I compares initial and final stocking and its distribution among canopy classes. It shows, above all, the reduction in the total number of stems during the 15- to 25-year period covered by the data. The reduction is most pronounced in the D-grade plots, where the present stocking is between one-half and one-third of that in the B-grade plots; but even in the latter the reduction amounts to more than half the original number of stems, except in the B-grade Norway spruce plot, where the stocking has only been reduced from 1,460 to 1,011 trees. In the B-grade Japanese larch plot, on the other hand, the stocking has been reduced from

2,340 stems to only 377; and in one of the B-grade Douglas fir plots (S.38), from 2,810 to 439. In the corresponding D-grade Douglas fir plot (S.37) the reduction has been from 2,989 to 193 stems, and in the D-grade Japanese larch plot from 2,595 to 143; and also in the other D-grade plots the present stocking is always less than 30 per cent. of the original. All tree classes have been affected by this reduction, but the lower ones more than the dominants and co-dominants, so that these two classes now form a larger proportion of the growing stock than they did at the start. This tendency is most pronounced in the D-grade plots, but is to be observed also in the B grades.

In the four pairs of plots which were established in 1923 or earlier it is unfortunately not possible to give the percentages of dominants and co-dominants separately for the first measurement, because of the slightly different classification in use at that time; but, together, these two classes accounted for 33 to 82 per cent. of the initial stocking, while now they account for 95 to 100 per cent. in the D-grade plots, 78 per cent. in the B-grade Norway spruce plot, and between 92 and 98 per cent. in all the other B-grade plots. In each pair of plots the percentage is higher in the D grade than in the B. In the Sitka spruce series and the second Douglas fir series, where the dominants and co-dominants are shown separately at establishment, the increase in these two classes is shown to be due mainly to a relative increase in the dominants, particularly in the D-grade plots of these series where the percentage of the co-dominants has actually decreased.

Table II shows how many of the trees allocated to each class at the first or second measurement have been removed in thinnings, and to which classes the survivors now belong. In the four pairs of plots where dominants and co-dominants were not distinguished at the time of establishment, the second measurement has been taken as the starting-point.

Of the original dominants none have been removed in the B-grade Norway spruce plot, and as many as 40 per cent. in the B-grade Douglas fir plot, S.38, where some dominants were blown by wind. The percentages for the other B-grade plots lie between these extremes. In each series the percentages of thinnings are higher in the D-grade plots, where they range between 31 per cent. in Norway spruce and 68 per cent. in the Douglas fir plot, S.79. Of the original dominants that are still standing, the majority have maintained their position as dominants, but some have become co-dominant and a few even sub-dominant.

In each plot a much larger proportion of the original co-dominants has been removed than of the original dominants, and although the actual percentages differ widely from plot to plot they are always higher in the D grade than in the comparable B-grade plot, except in the first Douglas fir pair (Plots S.37 and S.38), where the wind-blows among the dominants of the D grade have necessitated the retention of some co-dominants that would normally have been taken out in the thinnings. In this set 96 per cent. of the original co-dominants have been removed in the B-grade plot and only 89 per cent. in the D. In the B-grade Norway spruce plot only 10 per cent. of the original co-dominants have been removed, but in the other B-grade plots between 40 and 96 per cent. For the D-grade plots the corresponding percentage figures range between 79 and 99 per cent.

TABLE II. *The fate of the original growing stock*

Plot no.	Species	Thinning grade	Original dominants					Original co-dominants					Original sub-dominants				
			Original no. per acre	Removed %	Still standing as Doms. %	Co-doms. %	Sub-doms. %	Original no. per acre	Removed %	Still standing as Doms. %	Co-doms. %	Sub-doms. %	Original no. per acre	Removed %	Still standing as Doms. %	Co-doms. %	Sub-doms. %
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
S. 38	Douglas fir	B	698	40	43	12	5	644	96	..	3	1	245	100	..	..	..
S. 37		D	375	58	33	8	1	327	89	3	6	2	71	100	..	..	..
S. 80	Douglas fir	B	629	21	52	27	..	361	86	4	8	2	181	98	..	2	..
S. 79		D	653	68	27	5	..	303	99	..	1	..	88	100	..	..	..
E. 51	Norway spruce	B	603	..	92	8	..	379	10	14	35	41	277	76	..	..	24
E. 50		D	703	31	65	4	..	300	79	2	13	6	128	91	..	..	9
E. 70	Sitka spruce	B	1,097	17	63	19	1	767	65	8	20	7	400	95	..	4	1
E. 69		C	1,129	64	32	4	..	842	90	5	3	2	356	100	..	..	..
S. 29	Scots pine	B	293	8	79	10	3	334	40	19	37	4	194	88	..	4	8
S. 30		D	264	38	59	3	..	332	86	4	10	..	132	100	..	..	..
E. 55	Japanese larch	B	440	29	55	15	1	782	92	1	5	2	354	100	..	..	..
E. 54		D	344	61	38	1	..	234	97	3	..	..	74	100	..	..	..

Note: Trees originally classed as suppressed, dead, and dying are not shown in this table because they have all been cut out.
Douglas fir (*Pseudotsuga taxifolia* Brit.); Norway spruce (*Picea abies* Karst.); Sitka spruce (*Picea sitchensis* Carr.); Scots pine (*Pinus sylvestris* L.); Japanese larch (*Larix leptolepis* Gord.).

The small number of survivors among the original co-dominants is now distributed among the first three classes in varying proportions, but in most plots the majority have remained co-dominant. The fact that the number of those that have become dominant is of the same order as the number of those that have become sub-dominant does not indicate that co-dominants have an equal chance of moving up or down, but merely that the majority of those that move down are cut out.

The trees originally classed as suppressed are omitted from Table II, because they have fallen to the axe without exception. The great majority of the original sub-dominants have shared their fate: 24 per cent. survived in the B-grade Norway spruce plot, but most of these were classed as suppressed, dead, or dying at the last measurement, and the plot was to be clearfelled shortly afterwards and was therefore left unthinned. In the other B-grade plots the survival percentage lies between 0 and 12, and there is only one D-grade plot with any of the original sub-dominants surviving at all. This is the D-grade Norway spruce plot, where there are 11 (9 per cent.). Taking all the 12 plots together, only 5 per cent. of the original sub-dominants are left standing, 1 per cent. as co-dominants, 2 per cent. as sub-dominants, and 2 per cent. as suppressed, dead, and dying; and not a single one has become dominant.

Table II, in which the initial stocking has been taken as a starting-point, shows how many of the trees allocated to each class at the first measurement have been removed in thinnings and how many have either maintained or changed their original position in the canopy. In Table III the opposite approach has been adopted and the final stocking has been taken as the starting-point in order to show up even more clearly how the bulk of the present crop consists of trees that were dominants when young.

In all except two of the plots more than 90 per cent. of the present dominants have always been dominants. The two exceptions are the C-grade Sitka spruce plot and the B-grade Scots pine plot, in which the percentages are 87 and 79 respectively. All of the small number of dominants originating from other classes have come from the co-dominant class and not a single one from the sub-dominant class.

The origin of the present co-dominants is less uniform than that of the dominants. In the Sitka spruce and Douglas fir plots and in the B-grade Japanese larch plot the majority of the co-dominants have been recruited from the dominant class, and in the Norway spruce and Scots pine plots, and also in the D-grade Japanese larch plot, the majority have been derived from trees that have always been co-dominants. In nine of the plots none of the present co-dominants have come from the original sub-dominant class, and in the other three plots, all of which are B grade, a negligible number, namely, 2 per cent. in the Douglas fir plot S.80, 4 per cent. in the Sitka spruce, and 5 per cent. in the Scots pine.

Of the trees that are now sub-dominants most have come from the original co-dominant class, but in the B-grade Douglas fir plot S.38, 33 out of the 36 sub-dominants were originally dominants.

Of the present crops as a whole, between 55 and 98 per cent. are derived from the original dominant class, and in each pair of plots the percentage is higher in

TABLE III. *The original classes of the present growing stock*

Plot no.	Species	Thinning grade	Present dominants: No. per acre	Present dominants: Original classes: Doms. %	Co-doms. %	Sub-doms. %	Present co-dominants: No. per acre	Original classes: Doms. %	Co-doms. %	Sub-doms. %	Present sub-dominants: No. per acre	Original classes: Doms. %	Co-doms. %	Sub-doms. %	Present total growing stock: No. per acre	Original classes: Doms. %	Co-doms. %	Sub-doms. %
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
S. 38	Douglas fir	B	299	100	..	..	104	80	20	..	36	89	11	..	439	94	6	..
S. 37		D	132	92	8	..	51	61	39	..	10	30	70	..	193	81	19	..
S. 80	Douglas fir	B	340	96	4	..	201	83	15	2	10	30	70	..	551	90	9	1
S. 79		D	175	100	..	..	37	89	11	..	..	..	..	..	212	98	2	..
E. 51	Norway spruce	B	607	92	8	..	179	26	74	..	91	3	81	16	1,011*	60	33	7
E. 50		D	462	98	2	..	68	44	56	..	30	..	63	37	560	87	11	2
E. 70	Sitka spruce	B	746	92	8	..	379	54	42	4	75	21	72	7	1,200	76	22	2
E. 69		C	401	87	13	..	74	68	32	..	15	..	100	..	490	83	17	..
S. 29	Scots pine	B	293	79	21	..	163	18	77	5	38	21	40	39	494	55	40	5
S. 30		D	168	93	7	..	40	20	80	..	..	..	..	..	208	79	21	..
E. 55	Japanese larch	B	255	96	4	..	101	66	34	..	21	10	90	..	377	83	17	..
E. 54		D	140	94	6	..	3	100	..	..	..	..	..	..	143	94	3	..

* This total includes 134 trees now classed as suppressed, dead, and dying.

Douglas fir (*Pseudotsuga taxifolia* Brit.); Norway spruce (*Picea abies* Karst.); Sitka spruce (*Picea sitchensis* Carr.); Scots pine (*Pinus sylvestris* L.); Japanese larch (*Larix leptolepis* Gord.).

the D-grade plot than in the B grade, except in the first Douglas fir series, where wind-blows have affected the stocking. Between 2 and 40 per cent. of the present crops are derived from the original co-dominant class, and 0–7 per cent. from the original sub-dominant class; and for these two classes the percentages are usually higher in the B-grade plots than in their more heavily thinned counterparts.

It may be of interest to compare these findings with those of others who have done similar work. Flury (1) was probably the first to publish data on the distribution and movement of tree classes. He studied a considerably larger number of plots than are covered by the present investigation, and some of his series included A, B, C, and D grade plots, but his observations were confined to Norway spruce and beech (*Fagus sylvatica* L.), and to comparatively short periods of less than 10 years. He found that after the first thinnings the actual number of dominants is greater in lightly thinned plots than in heavily thinned ones, although this larger number represents a smaller percentage of the total growing stock (in this his data agree with ours); but after the third thinning he found that the dominants in the heavily thinned plots usually constituted not only a larger percentage of the smaller total growing stock, but were actually more numerous than in the lightly thinned plots, and in this his data differ from ours. This suggests that the rate of suppression in his lightly thinned plots was faster than in the British plots, which is confirmed by the detailed figures he gives for a B-grade Norway spruce plot, where within 8 years 67 per cent. of the original dominants had moved down one, two, or even three classes, and 96 per cent. of the trees that were sub-dominant at the end of the 8-year period had originally belonged to the dominant or co-dominant classes. He also states that the percentage of dominants generally increases with age, and in this his data again agree with ours.

Gutmann (3), who subdivides the dominants into pre-dominants and dominants, has published data covering a 12-year period in an A-grade Norway spruce plot. He found that of 43 pre-dominants 23 retained their position, 19 became dominant, and 1 co-dominant; and of 141 dominants 101 remained dominant, 2 moved up, 32 moved down one class, and 6 moved down two. Zimmerle (5) investigated the movement of tree classes in a series of three Norway spruce plots over the 31-year period from 1907 to 1938. They were 32 years old at the beginning of this period. Of the 1,200 original dominants in his A-grade plot, 28 per cent. had been removed by 1938, 52 per cent. were still dominant, 16 per cent. had moved down one class, and 4 per cent. two classes. The equivalent figures for his C- and D-grade plots were as follows:

	C grade	*D grade*
	%	%
Removed . . .	24	26
Dominant . . .	51	59
Co-dominant . .	16	12
Sub-dominant . .	8	3
Suppressed . . .	1	..

The fate of the original co-dominants was recorded only for the C- and D-grade plots. In the C-grade plot there were originally 1,412 co-dominants; of these only 28 were standing in 1938, of which 4 were co-dominants, 16 sub-dominants, and 8 suppressed. In the D-grade plot there were originally 1,644 co-dominants, of which 176 survived in 1938, 48 as dominants, 40 as co-dominants, 80 as sub-dominants, and 8 as suppressed trees.

These authors thus confirm the present findings that there is a general downward trend in the movement of tree classes, so that with increasing age an ever larger proportion of the growing stock consists of trees that were originally dominant. The only point of divergence appears to be that Flury's data suggest a faster downward trend than the British data and those cited by Gutmann and Zimmerle.

The downward movement is readily explained. As trees increase in size they require more space, and because this is not available in a fully stocked stand the number of trees is reduced, either by natural competition or by thinnings. Natural selection favours the most vigorous trees, and in even-aged stands such trees are nearly always the biggest, which have grown fastest in the past. If thinnings forestall the elimination of the weaker trees by natural competition, the position is not very different, because whatever dominants may be removed owing to their bad shape or for other silvicultural reasons, it is always the surviving dominants that derive most benefit from the increased growing space.

What bearing, if any, have the results of this investigation on thinning policy and practice? The fact that an even-aged stand in later life consists of a comparatively small number of trees, most of which were originally dominant, points to the importance of encouraging by judicious thinning at an early age the best shaped dominants at the expense of the less desirable ones. Sometimes also the removal of some of the latter dominants may be justified, in order to make room for a well-shaped co-dominant, because although the number of co-dominants that have moved contrary to the general downward trend and have become dominant is small, it is sufficient to suggest that if a co-dominant is freed early and drastically it has a fair chance of ending up in the final crop. The same does not appear to apply to sub-dominants, for a quite negligible number of them have become co-dominant, and not a single one dominant. This is not an argument for retaining a badly shaped dominant in the crop but merely indicates that if the said dominant is surrounded only by sub-dominants it is unlikely that any of them will develop sufficiently to take a leading place in the final crop. Unless the gap is a very large one, in most cases the more distant but still fringing dominants will utilize the space provided. The low survival value of the co-dominants and sub-dominants suggests that except when it is necessary to select a co-dominant as a potential final crop tree, it is not worth while spending too much time, when marking early thinnings, in choosing between individuals of these two lower classes. At the same time it may be desirable on silvicultural and economic grounds to prescribe the approximate number of co-dominants and sub-dominants that are to be removed in any one thinning.

Grateful acknowledgement is made to Messrs. H. L. Edlin and T. W. Irvine for their help in extracting and tabulating the data.

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APPENDIX I

Summary of measurements

Species Plot no. Thinning grade	*Date*	*Age in years*	*Main crop*								*Total crop*	
			No. of stems per acre	*Top ht.* ft.*	*Form factor*	*Mean girth at 4 ft. 3 in.*	*Basal area sq. ft.*	*Vol. under bark cu. ft.*	*Crown %*	*Bark %*	*Basal area sq. ft.*	*Vol. cu. ft.*
D.F. S. 37. D	1921	15	959	41	0·322	13	74·6	884	..	12½	160·2	1,489
	1945	38	193	93	0·393	38½	123·4	4,333	43	..	348·9	8,397
D.F. S. 38. B	1921	15	1,990	41½	0·301	12½	132·0	1,426	..	12½	151·6	1,457
	1945	38	439	91½	0·371	30½	179·5	5,792	..	..	345·4	8,722
D.F. S. 79. D	1926	21	989	44½	0·358	17	121·2	1,736	..	13	130·4	1,803
	1946	41	212	83½	0·371	36½	123·1	3,686	46	13½	266·1	6,628
D.F. S. 80. B	1926	21	1,133	43	0·367	15½	119·2	1,704	..	16	125·1	1,724
	1946	41	551	77	0·374	27½	183·1	4,846	14	39	246·6	5,849
N.S. S. 50. D	1922	19	1,160	32½	0·391	14½	106·8	1,296	..	10	142·9	1,594
	1942	39	560	67	0·438	29	207·8	5,884	39	8	321·4	7,708
N.S. S. 51. B	1922	19	1,375	32½	0·376	14	117·0	1,343	..	10	119·4	1,343
	1942	39	1,011	61½	0·417	23½	245·1	5,833	33½	8½	267·2	6,007
S.S. E. 69.† C	1923	16	1,610	32	0·336	13	113·1	1,162	..	12	139·8	1,339
	1938	31	490	55	0·455	21	94·3	2,266	29½	10	237·8	4,515
S.S. E. 70.† B	1923	16	2,175	27	0·307	12	136·6	1,045	..	12	140·6	1,045
	1938	31	1,049	57	0·416	19½	170·7	3,910	32	11	255·9	5,077
J.L. E. 54. D	1922	17	710	38	0·313	13	51·1	577	..	16	123·4	993
	1947	42	143	75	‡	34½	73·4	‡	..	..	243·1	‡
J.L. E. 55. B	1922	17	2,090	38	0·270	11½	119·4	1,143	..	16	124·1	1,145
	1947	42	377	72½	‡	25	103·6	‡	..	..	223·6	‡
S.P. S. 29. B	1921	35	920	41	0·339	18½	134·3	1,733	..	19	147·7	1,835
	1946	60	494	66½	0·350	29½	187·6	4,070	32½	17	258·2	4,971
S.P. S. 30. D	1921	35	750	43	0·334	19	120·2	1,562	..	19	157·1	1,912
	1946	60	208	62½	0·354	37½	126·1	2,723	38½	18	275·7	4,963

* Top height = average height of 100 largest trees per acre.

† Plots E. 69 and E. 70, although planted at the same time, immediately adjacent to one another, are not strictly comparable. The site of E. 69 was planted with home-raised 2+2+1 transplants on land which had previously been under cultivation but subjected to flooding. The site of E. 70 was planted with 3-year seedlings (brought from Germany) on land which was apparently outside the agricultural area and was certainly more boggy.

‡ Not recorded.

D.F. = Douglas fir (*Pseudotsuga taxifolia* Brit.).
N.S. = Norway spruce (*Picea abies* Karst.).
S.S. = Sitka spruce (*Picea sitchensis* Carr.).
J.L. = Japanese larch (*Larix leptolepis* Gord.).
S.P. = Scots pine (*Pinus sylvestris* L.).

APPENDIX II

Vegetation and location of plots

Species Plot no. Thinning grade	*Vegetation*	*County*	*Elevation and exposure*	*Slope and aspect*	*Soil*	*Geology*
1	2	3	4	5	6	7
D.F. S. 37. D	1921 nil. 1948 abundant: *Urtica* (a), *Oxalis* (a), *Myosotis* (f), *Viola* (f), *Ranunculus* (f), *Stellaria* (f), *Plagiothecium undulatum* (f), *Mnium undulatum* (f).	Inverness-shire	100 ft. Fully sheltered	Level	Loam over stiff gravelly glacial till	Old red sandstone
D.F. S. 38. B	1921 nil. 1946 scanty: *Rubus* (o), *Rumex* (o), *Plagiothecium* (o), *Thuidium* (o).					
D.F. S. 79. D	In 1926 nil. 1946 scanty: *Oxalis* (f), *Plagiothecium undulatum* (f).	Inverness-shire	250-ft. Moderately exposed	5° NW.	Rich loam over clay loam with pebbles	Old red sandstone
D.F. S. 80. B	1926 nil. 1946 nil.					
N.S. S. 50. D	1922 nil. 1942 nil.	Perthshire	700 ft. Moderately sheltered	3° NW.	Loam over boulder clay	Glacial deposit over mica schist
N.S. S. 51. B	1922 nil. 1942 nil.					
S.S. E. 69. C	1923 scanty: *Rubus* (a), *Galium* (f), *Urtica* (r). 1938 scanty: *Sambucus* (o), *Carduus* (o), *Urtica* (o), *Cerastium* (o), *Ranunculus* (o).	Northumberland	75 ft. Moderately exposed	3° SE.	Peaty loam over clay loam over boulder clay	Carboniferous limestone series
S.S. E. 70. B	1923 scanty: *Rubus* (a), *Galium* (f), *Urtica* (r), 1938 nil.					
J.L. E. 54. D	1922 nil. 1947 complete covering: *Rubus* (a), *Galium* (f), *Oxalis* (f), *Brachythecium purum* (f), *Thuidium tamariscinum* (f), *Plagiothecium undulatum* (f)	Wiltshire	850 ft. Moderately sheltered	Level	Clay loam	Greensand
J.L. E. 55. B	1922 nil. 1947 scanty: *Rubus* (f), *Oxalis* (f), *Galium* (f), *Aspidium* (f), *Luzula* (o)					
S.P. S. 29. B	1921 scanty: *Hypnum* (a), *Festuca* (f), *Oxalis* (f), *Anemone* (f). 1946 almost complete covering of grasses and mosses: *Galium* (f), *Oxalis* (f), *Hylocomium triquetrum* (f), *Aira flexuosa* (o), *Festuca* (a), *Hylocomium splendens* (f)	Aberdeen-shire	1,000 ft. Moderately sheltered	Level	River alluvium	Granite
S.P. S. 30. D	1921 scanty. 1946 *Festuca, Galium, Oxalis, Viola, Hypnum* and *Hylocomium splendens* (all f), *Aira flexuosa* (a), *Hylocomium triquetrum* (a)					

For species symbols of col. 1, see Appendix I.

In col. 2, a = abundant; f = frequent; o = occasional; r = rare.

SOME NOTES ON *PINUS LARICIO* (POIR) IN SPAIN

(With Map)

By SIR WILLIAM L. TAYLOR, C.B.E.

THE following notes are compiled from a paper entitled *Notes sobre el Pinus Laricio* recently received by the writer through the kindness of Señor Emilio Gonzales Esparcia, Ingeniero de Montes, Madrid. It is thought they may be of interest to foresters in Great Britain.

The natural habitat of the black pine (*Pinus laricio*, Poir, 1804, and *P. nigra*, Arnold, 1785) lies in southern Europe. The species occurs from Spain to the Caucasus, and from Austria to Cyprus, with a sub-variety in Algeria. Geographically the black pine is widely dispersed, occurring in isolated and widely separated places, without anywhere forming extensive tracts of forest, a fact from which forest botanists in Spain and elsewhere have inferred that the species is an ancient one which may be on its way to extinction. The large number of local habitats has given rise both to sub-species and to many varieties, often difficult to distinguish one from another except by reference to form, foliage, and minor characteristics.

The two chief sub-species are the Austrian and the Corsican pine. The Austrian is more coarsely branched, has dense, stiff, dark green needles, and is related to the Yugoslavian, Caucasian, and Crimean varieties. The Corsican sub-species is distinguished by a tall and graceful symmetrical stem and a lighter branching habit, with less dense, less stiff, and somewhat longer needles. With this sub-species are grouped varieties from Calabria, France, and Spain, and also the Algerian sub-variety (var. *hispanica-rifana*). As a link between these two groups there is the Italian pine, *P. villetta-barrea.*

The relationship of the numerous varieties of *P. laricio* is given in the following table:

Pinus laricio-austriaca var. *dalmatica*
„ *bosniaca*
„ *taurica*
„ *pallasiana*
„ *caramanica*
Pinus villetta-barrea
Pinus laricio-corsicana var. *calabrica*
„ *cebennensis*
„ *monpeliensis*
„ *salzmannii*
„ *hispanica*

The Spanish forestry authority Maximo Laguña, in his work *Flora Florestal Española*, written at the end of the nineteenth century, did not admit Spanish

varieties of *P. laricio*, citing only two positive botanical varieties, described by Wilkomm—one, var. *latiscuama*, found in central Spain, and another, var. *angusticuama*, from the Lerida mountains. Since this work was published it has been confirmed that no special Pyreneean varieties occur, the trees growing in the Pyrenees being *P. laricio* var. *hispanica*. Notwithstanding this regional botanical uniformity, *P. laricio* in Spain presents many different features arising from the varied conditions in which it grows.

The common names by which the Spanish varieties are locally known are:

The Salt Pine (Jaen);
The Black Pine (Cuenca, Teruel);
The Pudio Pine (Burgos, Soria);
The Cascalbo Pine (Avila);
The Gargallo Pine (Lerida).

In general, Spanish varieties are referred to collectively as *pino laricio*, the botanical designation being adapted to the Spanish to avoid confusion with other species.

With slight differences these trees resemble Corsican pine. The botanical features are, in the main, typically those of the sub-species *corsicana*. The trees attain heights up to 45 metres and develop long, clean stems, comparable with the best examples of Corsican pine. The bark of young trees is ash coloured, becoming thick and corrugated for the first 3 metres or so of height, as the tree ages, but retaining a silvery hue between the fissures, for which the Spanish term is *espejuelos* or little mirrors. Crowns tend to flatten out or become rounded at maturity, but in the younger stages, where spacing is satisfactory, form is pyramidal. Foliage is retained in clusters at the ends of the branchlets, and needles of previous years are not persistent. Buds are pointed, cylindrical, very resinous, and in colour reddish-yellow with a whitish base. The flowering season is from March to May; the cones are oviform-conical, somewhat curved, almost sessile, horizontal or slightly inclined downwards, from 5 to 8 cm. in length by 2·5 to 3 cm. broad, those from central Spain being larger than those from the Pyrenees. Cones ripen in the second autumn and seeds are shed the following spring. A kilogram of clean seed is stated to contain approximately 31,000 seeds, whereas English text-books give an approximation of 32,000 seeds of Corsican pine to the lb. Seed years are irregular, the seed being abundant every 3 to 5 years on the average.

These pines are storm-firm. Although the tap root does not always develop normally, side roots extend at medium depth and grip the rocky subsoils firmly. They are perhaps the longest-lived of all species of *Pinus* in Spain. Trees over 500 years old have been recorded after felling, but these ancient specimens are rapidly becoming rare. As late as the beginning of the present century, in Serrania de Cuenca there were stems of 80-cm. diameter at a height of 6 metres; exceptional trees have contained 20 cubic metres in total volume. In favourable situations timber of first-class quality has been produced, described as being 'up to the standard of Scots pine' (*Pinus sylvestris* L.), with which the timber competes in the markets. The Scots pine is preferred for joinery work, and the

Corsican pine for building construction. The resin is of good quality, but the yield is small by comparison with that from maritime pine (*P. pinaster* Ait.), so that tapping is not economic except when resinous products are scarce.

With few exceptions the present habitats of *P. laricio* in Spain are confined to the eastern parts of the peninsula, but some restocking has been successful on the western side. The most important locations are:

1. Gerona, Pyrenees: pure stands or in mixture with Scots pine.
2. Barcelona, Sierra de Baga: mixed stands (*P. laricio* and *P. sylvestris*).
3. Tarragona, Sierra de Prades: mixed stands (*P. laricio* and *P. sylvestris*).
4. Lerida, Seo de Urgel: pure stands.
5. Huesca, San Juan de la Pena: mixed stands.
6. Burgos: a small area in mixture with Scots and maritime pine.
7. Soria, Navaleno, and San Leonardo: occurs singly with groups of larch (*Larix europaea* DC.) between areas of Scots and maritime pine.
8. Avila, Valle del Alberche: poorly stocked woods of very ancient trees with maritime pine encroaching.

The two largest groups in which *P. laricio* is the predominant species are—(i) Those which have their centres of dispersion in the mountains of Cuenca (9; see map), extending between the mountain ridges of Molina, Albarracin, Maestrazgo, and others. (ii) Those at the source of the rivers Guadalquivir and

Segura, i.e. the Sierras Cazorla (10 and 11; see map). The former region has been surveyed and *P. laricio* has been found to predominate over 90,015 hectares, but there are also other blocks of forest in the locality, of equal area, over which the principal species are *P. sylvestris* L. and *P. pinaster* Ait. In the second group *P. laricio* becomes almost pure at the higher elevations and on the calcareous plateaux, up to the limits of tree growth, but at the lower levels *P. pinaster* L. and *P. halepensis* Mill. come in. To the foregoing very considerable aggregate area must be added the smaller centres of Albacete, Sierra de Alcaraz, and Yeste (12); Granada, La Sagra (13); Almeria, Sierra Maria (14), and Murcia, El Carche (15). Altogether, including the Pyrenees, the total extent of forest over which *P. laricio* predominates exceeds 300,000 hectares, the species occurring in mixture with other pines over a further like area. (The numbers in brackets refer to the stations marked on the map.)

In general it can be said that the natural habitat of the Spanish *P. laricio* lies within the *Castanetum* zone. Climate is dry and extreme, modified in part by relief afforded by the mountain ranges. Rainfall is on the whole light and badly distributed, varying from 500 to 1,500 mm. per year, according to locality, with a regular period of summer drought and a further dry period in autumn. Evaporation is intense, annual temperatures showing a variation of 40° C., with maxima of 30° C. and minima of —10° C. The growing season averages from 4 to 6 months.

In Spain *P. laricio* is described as a mid-mountain species, at its best at elevations of 1,000 to 1,500 metres. However, it occurs in mixtures down to 800 metres and is to be found on sites up to 1,800 metres. The most important stands occur on the calcareous clays of the Cretaceous and Jurassic formations (Serrania de Cuenca and Sierras de Cazorla and Segura); but the species also tolerates siliceous soils, and examples occur on the granitic soil of the eastern slopes of Sierra de Credos, where, however, *P. laricio* is already almost supplanted by *P. pinaster* Ait. Soils vary widely in depth; where they are light, deep, and moist (south of Cuenca and Segura), the stands are of normal density and are composed of healthy trees, of vigorous growth, with tall, well-formed stems. In other parts, where soil depth is irregular, the stands are more sparse, and stems are of unequal growth and development, regeneration often proving difficult. On the borders of Soria and Burgos (Hontoria del Pinar) conditions support only sparsely scattered trees growing in company with '*sabina*' (*Juniperus thurifera* L.). In spite of the fact that *P. laricio* is a calcicole species, it cannot stand high pH values. On burnt patches it does not regenerate, or only with difficulty, due no doubt to the increase in basic elements resulting from fire.

A marked characteristic of Spanish types of *P. laricio*, in spite of their resistance to drought, is their toleration of shade, in contrast to the light-demanding tendency of the other Iberian pines. It is not unusual to find young trees growing well, and retaining 15 to 20 whorls of green branches, for more than 20 years beneath the shade of an over-wood; and on sunny slopes an understory is frequently to be found beneath the canopy of the older trees.

Ecologically it is believed that the presence of pine-trees is indicative of regression. Spanish forest ecologists are inclined to the opinion that large parts of the

area to-day occupied by *pineta laricionis* bore, in no very remote times, a *quercetum* climax, which, on disturbance by man and animals, has been replaced by the pines. The anthropo-zoogenic interferences still threaten and encourage the invasion of less exigent species such as Scots and maritime pines. Thus extensive tracts of *P. laricio* have been lost, as in the valley of the Alberche, where only a few ancient relics survive among the maritime pine stands. The influences favouring these regressions are deplored by Spanish foresters. Soils have degenerated to the extent that it is considered impossible to restore a climax vegetation, compatible with mean climatic conditions. Consequently the pines are now being accepted as the biological optimum.

In Spain *P. laricio* forest is usually treated by successive uniform thinnings. The rotation is 120 years, with a regeneration period of 20 years. For regeneration the periodic block is divided into six strips, which are successively cut over. However, serious difficulties have been encountered in regard to natural regeneration, which has not been achieved within the stipulated period. Efforts are being made to extend the regeneration period to 30 years, to modify the classes to be cut, and to effect some preparation of the ground. A minority opinion puts failure down to errors of principle, and thinks that the methods used, imported with slight variations from central Europe, are inadequate for Spanish conditions, as they do not take into account the modifications which a different climate introduces in vegetative conditions. The latter opinion advocates the building up of even-aged stocks by preparing the ground and, where necessary, sowing direct or planting; because apart from other reasons, all the stocks of this kind which have been studied have been observed to yield an average growth ten times superior to the samples of natural forest hitherto examined.[1]

Varieties of *P. laricio*, other than native varieties, have been tried. Austrian pine has been found valuable in mountain zones characterized by very dry calcareous soils, in rigorous conditions of climate. Exotic varieties of the Corsican sub-species have been tried only on a small scale or not at all, so that experience of their value for acclimatization has been insufficient so far.

For a translation of Señor Esparcia's very interesting report the writer is indebted to Mrs. M. P. Lewis of the Forestry Commission's Research Station at Alice Holt, Farnham, Surrey.

[1] Bolanos, Martin (M.), *Ensayo de investigación indirecta sobre origen, desarrollo, y producción del Monte Alto.* Madrid, 1947.

A STUDY OF THE VARIATION OF MORPHOLOGICAL CHARACTERS WITHIN TREE SPECIES WITH SPECIAL REFERENCE TO EUROPEAN LARCH OF DIFFERENT PROVENANCES (*Larix decidua* Mill.)

By J. C. VARMA

INTRODUCTION.

The meaning and importance of provenance.

IN forestry the term 'provenance' refers to the place of origin of trees or their seed. It signifies the geographic region where a type is found, with its climatic, edaphic, and physiographic factors. (There is general acceptance of the fact that a widely distributed species is made up of types which show differences in their morphological and biochemical characters and have developed in different environments.) Though the study of provenance is of more or less recent origin, compared with other branches of forestry, yet a considerable amount of work has been done (7) on the discovery and isolation of the climatic and physiographic races that will grow best in any particular locality. For over half a century investigators have realized, to an increasing extent, the importance of seed origin or provenance, particularly in Europe, where artificial regeneration of forest trees has been common practice for a long period.

The matter was not of such great significance in the remoter past when natural regeneration was the main source of seedlings, and man did not interefere so much with the natural distribution of any type. The problem has become a much more complicated one with the adoption, for economic reasons, of artificial regeneration and the introduction of exotics. Moreover, it has come to be realized increasingly that the types which were hitherto considered pure are in reality a complex of genotypes, with very variable characters. The differences may be so slight and difficult to detect that it may not be possible to identify them on purely morphological characters; yet they may be significant enough to make it necessary to define the different strains, as climatic or local races. Turesson (10) was of opinion that species are made up of ecotypes or natural biotype groups, only those types which are adapted to the climatic and edaphic factors of a locality being perpetuated. In other words, 'provenance is a matter of genecology or race-ecology, a species extending its range by selection of biotypes'. This ecological theory of the origin of races, with more emphasis on heredity, is also supported by Busgen and Münch (2). It may be stated, however, that neither of these two factors can be studied in isolation from the other. The race is a resultant of the interaction of the genotype and the environment.

With the realization that most, if not all, species consist of races or strains which have developed under specific environments, the problem of provenance may be stated briefly as one that involves the discovery of the climatic races that

will grow best in any particular region or locality. Generally their characters are heritable. It follows, therefore, that where two regions have a more or less similar climate, the development of a race imported from the one region to the other may be similar in the new environment to what it was in the old. But where bigger changes of environment are involved, the imported strain may become decadent in early life, develop poor form, show marked susceptibility to climatic extremes, or fail to survive. It is the purpose of provenance studies in such cases to determine the chances of success of an exotic race before large-scale imports are made.

Provenance studies rest upon the establishment of test plantations with seed from various sources, in extensively replicated plots. For satisfactory work, a thorough knowledge of the ecological factors both in the place of origin and the planting locality is necessary. An ecological approach is essential in order to strip off the mask of environment from any local type.

To sum up, provenance studies aim at finding strains of trees with particular genetical constitutions, and determining the effect of various environments upon them. The results should find practical application in the use of the provenance most suitable for each environment.

The bulk of the work on provenance studies in larch has been concerned with *L. decidua* Mill. (*L. europaea* DC.), the European larch. Experiments on European larch provenance have been made on the Continent to ascertain the climatic or physiological races that will grow best in any particular locality. According to Herrmann (4), four races are commonly distinguished, the Alpine, the Carpathian, the Polish, and that found in Prussian Silesia and, in Czechoslovakia, in the Sudeten mountains.

The existence in Germany of mature larch stands of outstanding vigour and quality, side by side with young plantations which proved a failure, led Münch (6) to consider the importance of provenance as a factor governing health and disease. He concluded that the failures were due to the use of unsuitable races, mainly Alpine, and that the solution of the problem was to be found in the selection of a race suited to the climate of the locality concerned. The observations of Burger (1) on larch provenance experiments in Switzerland agree with this conclusion, also.

The work of Macdonald (5), Rubner (8), and Wettstein (11) shows that races of larch may be selected for yield, because in any given locality they differ significantly in the volume of timber produced, as also in growth rate and height. The first worker also points out racial differences in shape and branching habit. The report of Rubner (9) on 10-year sample plot trials with larches of different seed origins is important. The fastest early growth was exhibited by the Sudeten race; the Alpine race, though slower, could still be regarded as fast growing; and the Scottish larch grew about as fast as the fast growing Alpine races.

The purpose of the present investigation.

The European larch is one of the most important exotic conifers introduced into Great Britain and has been extensively planted. It is one of the most

economically profitable species under favourable conditions of growth but has met with varying success in different regions. The behaviour of larch races when taken outside their native range suggests strongly that choice of an unsuitable provenance has been a chief factor in the frequent failure of plantations. The present work is concerned with the examination of characteristics of four provenances of larch, grown in two markedly differing situations. Its aim has been to discover not only which race has grown best, but also whether measurable attributes such as angle of branching, or length of branch, at a given age, revealed any significant differences between the provenances.

Hitherto, work along these lines had been carried out mainly from a subjective point of view, and without the use of measurements which may be repeated in a purely objective manner. It is believed that the objective approach here attempted, with a statistical background, to the ecological and genetical problems of the European larch should help to place the identification of races on a more secure basis.

MATERIAL.

Two series of observations were carried out, one at Halfway and the other at Mynydd Ddu forests. Both these places have replicated sample plots of four provenances of European larch, planted as 2-year transplants in March 1940. The four provenances, according to their place of origin are:

1. Bohemia, referred to hereafter as A.
2. Darnaway (Scotland), referred to hereafter as B.
3. Austria (Inn Valley), referred to hereafter as C.
4. Trentino, referred to hereafter as D.

(The measurements tabulated were made in March 1947.)

Halfway Experimental Plots.

Halfway Forest lies in the extreme west of Brecknockshire. The surrounding country is mountainous. The plots are at 900 feet elevation and occupy the upper slope of the eastern flank of a ridge, fairly near its top. The top row of plots is very exposed.

The rock from which the soils are derived is an arenaceous shaly Silurian flagstone. The soil is extremely variable and seems to be determined by local topography. The type of soil is very well reflected in the ground flora. Along gentler gradients, 10° to 15°, the soils are occupied by *Rubus fructicosus* L. and are comparatively deep, of the Brown Earth type, crumbly, loose, and mixed with small shale fragments. The soils under *Vaccinium myrtillus* L. and *Deschampsia flexuosa* Trin. are along steeper parts, with a gradient varying from 15° to 20°; they are of the Degraded Brown Earth type, with a layer of raw humus, and are more compact and shallower. The soils occupied by *Calluna vulgaris* Salisb. are on the steepest gradients, 20° to 30°, are the shallowest and most compact, and give indications of impeded drainage. The ground flora was taken as an index of soil types in selecting trees for measurement.

Mynydd Ddu Experimental Plots.

This region lies in the eastern part of Brecknockshire, in the heart of the Black Mountains. The plots are on the lower part of a fairly gentle slope and at an elevation of 1,100 feet. The ground falls 200 feet to the valley bottom below and rises to over 2,000 feet on the mountain top above. The valley at this point, though deep, is wide and open. The aspect of the plots is north-easterly, and while well sheltered from the west by the rising slope, they are exposed to the north and north-easterly valley winds.

The soil is derived from Old Red Sandstone. It is shallow but less so than at Halfway. It is homogeneous and of the Brown Earth type, being a crumbly, loose, fresh, sandy loam, with few stones and a free drainage. The soil over the plots is fairly even and fertile, as is shown by an even growth of *Rubus fruticosus* L. throughout.

METHODS.

Height measurements.

The height measurements were taken for over fifty trees in each of the plots sampled. An ordinary 6-foot scale was used for this purpose. For taller trees at Mynydd Ddu a small ladder was used. The shape of the stem was taken into consideration while recording the heights. Three categories of stem were recognized —straight, basal bending, and multiple bending. The presence or absence of the leading shoot was also recorded.

Other measurements.

For other measurements three trees were selected in each sample assessed. At Halfway one sample for each race was taken, on four vegetation types—(1) *Rubus*, (2) Exposed *Vaccinium*, (3) Unexposed *Vaccinium*, and (4) *Calluna*, resulting in a total of 16 samples and 48 trees. At Mynydd Ddu one sample of each race, in three different places, was taken, resulting in a total of 12 samples and 36 trees. To ensure proper randomization of the sample trees selected, Tippet's tables were used.

(*a*) *Length of branches.* For convenience, the crown of the tree was divided into four zones—northern, southern, eastern, and western, with the help of a prismatic compass. The length of all the branches arising from the main stem, from the base to the commencement of the shoot of the current year, was measured.

(*b*) *Angle of branching.* The angle which the individual branches subtended with the main axis of the stem was measured. For quickness and reasonable accuracy, a locally designed protractor was used. This consisted of two equal metal arms, joined at right angles to each other. Between the extremities was fixed a metal strip, a quarter of a circle in shape, graduated at intervals of 5°. At the junction of the two arms was attached a movable pointer. In measuring the angle of the branches, one arm of the instrument was placed in line with the main stem at the junction of the branch and the pointer was alined with the branch. The length of the pointer served to give the mean trend of the branch if it was abnormally bent.

CONCLUSIONS BASED ON STATISTICAL ANAYLSIS.

Halfway.

TABLE I. *Length of branches and height in in. (Halfway Forest).*

	Race A Bohemia		*Race B Darnaway*		*Race C Austria*		*Race D Trentino*	
Vegetation type	*Br. l.*	*Ht.*	*Br. l.*	*Ht.*	*Br. l.*	*Ht.*	*Br. l.*	*Ht.*
(1) *Rubus*	21·0	94	23·3	96	15·7	66	19·7	102
	20·1	108	22·3	102	14·0	36	18·1	84
	23·7	104	20·5	82	13·4	50	17·9	90
(2) Exposed *Vaccinium*	18·6	72	19·4	93	13·8	71	16·7	72
	18·5	108	18·4	74	14·2	46	16·9	63
	15·6	66	16·5	86	10·2	43	12·8	60
(3) Unexposed *Vaccinium*	20·0	84	22·7	138	17·0	51	19·3	100
	21·9	86	24·1	144	11·8	48	18·8	96
	17·8	100	21·8	96	16·8	84	18·2	89
(4) *Calluna*	19·0	91	17·1	84	15·9	86	20·4	94
	15·8	69	18·7	88	12·9	72	15·6	79
	16·6	84	18·7	81	11·5	60	17·0	62

Means for races	*A*	*B*	*C*	*D*	*S.E.*
Height (in.)	89·70	97·0	59·40	82·60	±4·10
Branch length (in.) . . .	19·12	20·29	13·93	17·62	±0·52
Means for vegetation	(1)	(2)	(3)	(4)	
Height (in.)	85·3	71·2	93·0	79·2	±4·10
Branch Length (in.) . . .	19·22	15·87	19·18	16·6	±0·52

(S.E. = Standard Error.)

Race A. *Bohemia*
„ B. *Darnaway* (Scotland)
„ C. *Austria* (Inn Valley)
„ D. *Trentino*
} and so throughout the Tables.

Planted March 1940 (2-year transplants). Measured March 1947.

Table I shows mean heights and branch lengths in the plots at Halfway Forest, classified according to race and vegetation. Both the height and branch length of the race Austria (Inn Valley) are very much lower than in the other three races, the differences being highly significant. Trentino is lower in height than Bohemia and Darnaway, but the differences here are smaller, and only Darnaway-Trentino just reaches significance.

The vegetation means show, for both measurements, very similar values for *Rubus* and unexposed *Vaccinium*, and also for *Calluna* and exposed *Vaccinium*: the first pair are consistently greater than the second. Differences between vegetation types seem to be little affected by differences of race, except that for Austria the heights are lower for *Rubus* and higher for *Calluna* than expected.

Analysis of covariance between heights and branch lengths shows that, within any race-vegetation class, there is a correlation between the two measurements, an increase of 1 inch in height corresponding to an increase of 0·07 inch in branch length. This effect, however, is too insignificant to allow the race and vegetation differences in branch length to be attributed to the corresponding differences in height. Adjustment of inequality in height by means of regression thus fails to account for most of the branch-length differences, which remain significant except for that between Bohemia and Darnaway.

Mynydd Ddu.

TABLE II. *Length of branches and heights in in. (Mynydd Ddu Forest).*

	Race A Bohemia		*Race B Darnaway*		*Race C Austria*		*Race D Trentino*		
Block	*Br. l*	*Ht.*	*Br. l*	*Ht.*	*Br. l*	*Ht.*	*Br. l*	*Ht.*	
1	31·1	156	33·7	186	23·0	108	29·0	168	Planted 1940. Measured March 1947
	22·7	108	28·2	138	22·4	108	21·5	102	
	35·1	156	27·0	114	23·9	102	23·2	114	
2	23·2	96	32·7	150	21·4	84	30·9	164	
	36·9	162	26·8	138	21·0	90	26·7	114	
	26·4	108	30·1	132	21·2	84	26·0	108	
3	23·2	108	28·1	120	20·8	81	24·6	140	
	36·9	144	30·9	150	23·0	108	26·5	162	
	26·4	138	27·2	102	18·7	72	24·7	114	

Races	*A*	*B*	*C*	*D*	*S.E.*
Mean height (in.) . . .	130·70	136·70	93·0	131·80	±8·30
Mean branch length (in.) . .	29·10	29·41	21·71	25·90	±1·35

Table II gives the data for height and branch length at Mynydd Ddu and shows that races A, B, and D differ but little in height, while C is significantly lower than all three. In branch length A and B are substantially greater than D, which in turn is significantly greater than C. The regression of branch length on height within races is sufficient to explain the difference in branch length between C and D, but adjustment for height differences still leaves A and B significantly greater than C and D.

Analysis of the data in Table III shows that the differences between races at Halfway with regard to the angle of branching are not significant and may be due to random variation. There are, however, significant differences between the mean angles of branching for vegetation types; unexposed and exposed *Vaccinium* give very similar values, but *Rubus* is substantially higher than *Calluna*.

Table IV shows that, with regard to the angle of branching at Mynydd Ddu, races A, B, and D have similar values, all markedly greater than C. These Mynydd Ddu plots thus contrast with those at Halfway in suggesting that under some circumstances differences in angle of branching may appear as a racial characteristic.

TABLE III. *Mean angle of branching in degrees (Halfway Forest).*

Vegetation type	*Race A Bohemia*	*Race B Darnaway*	*Race C Austria*	*Race D Trentino*
(1) *Rubus*	77·8	70·2	74·2	78·1
	62·3	70·5	72·3	73·7
	62·3	71·2	68·5	75·2
(2) Exposed *Vaccinium*	61·8	71·8	50·4	74·5
	63·6	61·9	55·6	66·3
	69·7	66·1	68·7	59·3
(3) Unexposed *Vaccinium*	65·1	61·7	66·8	76·5
	62·8	67·4	48·2	59·3
	73·2	66·4	69·5	66·5
(4) *Calluna*	74·7	62·0	73·3	56·5
	66·6	70·7	50·1	42·5
	63·9	63·5	34·0	52·4

Races	*A*	*B*	*C*	*D*	*S.E.*
Mean angles . . .	66·7	66·9	61·0	65·1	±2·28
Vegetation types . .	(1)	(2)	(3)	(4)	
Mean angles . . .	71·1	64·1	65·3	59·2	±2·28

TABLE IV. *Mean angle of branching in degrees (Mynydd Ddu Forest)*

Block	*Race A Bohemia*	*Race B Darnaway*	*Race C Austria*	*Race D Trentino*
1	69·7	89·0	55·5	69·8
	71·4	61·5	76·2	73·4
	75·4	65·9	65·4	80·6
2	66·8	67·6	62·0	80·3
	77·5	69·1	52·0	71·6
	77·5	80·6	70·0	86·7
3	75·0	68·5	57·6	62·3
	75·4	74·3	74·5	76·1
	84·4	61·8	52·7	77·7

Races	*A*	*B*	*C*	*D*	*S.E.*
Mean angle of branching	74·8	70·9	62·9	75·2	±2·8

Table V shows that at Halfway races A and B have a significantly higher proportion of 'straight' stems than have races C and D, and that this proportion is significantly lower on Exposed *Vaccinium* than on any of the other vegetation types.

It is shown also that races A and B have a significantly lower proportion of 'leaderless' stems than have races C and D: and *Rubus* and Unexposed *Vaccinium* have a lower proportion of such stems than Exposed *Vaccinium* and *Calluna*.

TABLE V. *Percentages of shape of stem and absence of leading shoot (Halfway Forest)*

Vegetation type	*Race*	*Straight*	*Basal bending*	*Multiple bending*	*Leader-less*
(1) *Rubus*	A (*Bohemia*)	79·80	3·01	17·19	1·50
	B (*Darnaway*)	85·34	1·33	13·33	5·33
	C (*Austria*)	73·48	8·33	18·19	11·11
	D (*Trentino*)	72·47	5·79	21·74	8·69
(2) Exposed *Vaccinium*	A	64·0	8·00	28·0	6·0
	B	68·33	5·00	26·66	8·33
	C	52·18	10·87	36·95	10·87
	D	55·11	18·36	26·53	12·24
(3) Unexposed *Vaccinium*	A	74·38	8·97	16·66	3·84
	B	88·53	1·85	9·62	1·85
	C	51·85	11·11	37·03	11·11
	D	69·10	9·09	21·81	5·45
(4) *Calluna*	A	79·93	7·69	15·38	7·69
	B	79·69	6·77	13·54	2·38
	C	67·87	14·28	17·85	14·28
	D	65·80	10·52	23·68	9·21

Races	*A*	*B*	*C*	*D*	*S.E.*
Mean index % of straight stems . .	59·3	64·2	51·6	54·1	±1·7
Vegetation types	(1)	(2)	(3)	(4)	
Mean index % of straight stems . .	61·8	50·7	58·0	58·6	±1·7
Races	*A*	*B*	*C*	*D*	*S.E.*
Mean index % leaderless stems . .	12·6	11·4	20·0	17·0	±1·4
Vegetation types	(1)	(2)	(3)	(4)	
Mean index % leaderless stems . .	14·5	17·6	13·0	16·0	±1·4

In Tables V and VI each of the percentages was converted, for statistical analysis, to an 'equivalent angle' (see Fisher and Yates (3), Table XII), in order to avoid the heterogeneity of variance encountered with very small, or very large percentages. In the summary tables the mean angle is used as an index for comparing different groups of observations.

Table VI shows that at Mynydd Ddu race B has a significantly higher proportion of straight stems than the other races; C is low but scarcely significantly lower than A and D.

DISCUSSION.

A study of the provenance experiments at Halfway and Mynydd Ddu and an examination of the above results point towards several interesting conclusions.

The most striking of these is the outstanding superiority of the Darnaway (Scotland) race of European larch over the others, not only in regard to height growth, but also in stem form and the retention of the current shoot. The Austrian (Inn Valley) race is the worst, while the Bohemian is relatively good and comes a close second to the Darnaway.

TABLE VI. *Percentages of shape of stem and absence of leading shoot (Mynydd Ddu Forest)*

Block No.	*Races*	*Straight*	*Basal bending*	*Multiple bending*	*Leaderless*
1	A (*Bohemia*)	78·93	..	21·07	..
	B (*Darnaway*)	86·00	4·00	10·00	..
	C (*Austria*)	51·71	3·84	36·45	2
	D (*Trentino*)	78·19	..	21·81	2
2	A	68·19	..	31·81	..
	B	88·89	..	11·11	..
	C	61·55	4·61	33·84	..
	D	72·61	..	27·39	..
3	A	67·80	3·39	28·81	..
	B	70·00	4·00	26·00	..
	C	62·03	5·06	32·91	..
	D	64·00	..	36·00	..

Races	*A*	*B*	*C*	*D*	*S.E.*
Mean index of % of straight stems. .	58·0	65·1	51·5	57·9	±2·2

Differences in the length of branches between the four races are highly significant and, as before, the Darnaway (Scottish) race has the longest and the Austrian the shortest branches. These differences cannot be accounted for on the basis of height differences and, therefore, the vigour of the tree alone, as is seen from the analyses of covariance for both Halfway and Mynydd Ddu. Branch length is, therefore, strongly suggested as a morphological character which may be taken as racial and so of service in classifying provenances. Differences in height growth between the Darnaway (Scottish) and its close second, the Bohemian races, and the Trentino and Austrian (Inn Valley) races are also significant and of use in classifying provenances.

The data show a certain amount of differences between the various races in regard to the mean angle of branching. These are not significant at Halfway and may be due to random variation. Hence the angle of branching cannot in this case be taken to show any racial differentiation. But at Mynydd Ddu the angle of branching of the Inn Valley race is significantly smaller than that of the other races. It is plain, therefore, that any comparison between the races in regard to this character, as well as for any others, should be made under similar ecological conditions and can only apply to such conditions. On better soils the different

races may give closer figures than on poorer ones (e.g. compare figures for *Rubus* with *Calluna*, Table III). At the same time, the range of variation in this character within all races, and for the Inn Valley particularly, is very wide (e.g. 68·5° to 74·2° on *Rubus*; 50·4° to 68·7° on Exposed *Vaccinium*; 48·2° to 69·5° on Unexposed *Vaccinium*; and 34·0° to 73·3° on *Calluna* at Halfway, Table III). The intra-racial heterogeneity thus exhibited may be due to the fact that the cultures assigned to the various races may be the outcome of random seed collection over a range of individuals varying significantly in character. Thus it lays the experiments open to criticism. For none of the cultures bear any specification as to the locality of origin, or the record of mother-trees from which the seed came, beyond indicating enormous ranges of distribution, such as Bohemia, Inn Valley, &c.

Observations at Halfway are of particular interest in view of the fact that vegetation means for almost all features show comparable values between *Rubus* and Unexposed *Vaccinium*, and *Calluna* and Exposed *Vaccinium*. The low figures obtaining under Exposed *Vaccinium* for all characters indicate the marked effect which exposure has on tree growth.

The striking difference in growth and vigour brought about by a relatively fertile soil and better aspect, as at Mynydd Ddu in comparison with Halfway, hardly needs stressing. In fact the extremely poor performance of all four races at Halfway makes it very doubtful whether it will be at all worth while planting European larch in such places.

The most interesting and successful of the four provenances, that called Darnaway, is presumed to have been raised from seed collected from larch in Darnaway Forest, Morayshire. The origin of its ancestors appears to be unknown. In all its characters, as well as the regression for height and branch length, it shows a great similarity to the Bohemian race. Possibly the Bohemian race may be the one from which the Darnaway was derived. It is very likely that during the course of cultivation in these islands a certain amount of natural selection has taken place. The suggestion is put forward, therefore, that it may be an instance of an isolation of races from an already existing complex, rather than a transformation of race-characters. It would appear that this must be true for any Scottish provenance of European larch: hence to consider a Scots race as having been naturalized and modified in comparison with its parent stock, within a generation or so, would be to take too liberal a view of 'Gene-plasticity'.

The author wishes to express his sincere thanks to Mr. W. R. Day, under whose guidance this work was carried out, and to Mr. D. J. Finney for his valuable help in statistical matters. Thanks are due also to the Forestry Commission for permission to work in their experimental plots and for field assistance in the actual work. He is indebted in particular to Mr. A. A. Zukowski for his keen interest and valuable suggestions.

SUMMARY.

1. Provenance experiments on races of European larch (*Larix decidua* Mill.) at Halfway and Mynydd Ddu, Wales, have been studied. The race Darnaway (Scotland) has proved to be the best, and the race Austria (Inn Valley), the worst.

2. The length of the branches is a morphological character which distinguishes the race; the angle of branching does not.

3. Height growth is also a racial character, and may be used to separate races under similar soil and vegetation conditions.

4. There are significant differences between provenances in respect of straightness of stem and liability to lose leading shoots.

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THE ELIMINATION OF BIAS DUE TO EDGE-EFFECTS IN FOREST SAMPLING

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1. INTRODUCTION.

IN the sampling of a forest for the estimation of timber volume, or indeed for the estimation of any other quantitative characteristic of the forest, careful formulation of rules for determining the situation of individual sampling units is essential if the danger of biased estimation is to be avoided. The guiding principle may be independent random selection of each unit, with or without stratification, or use of a systematic pattern of units, all of which are fixed as soon as a random site is selected for the first (1). Providing that the appropriate rules are rigorously followed, either of these procedures gives an objective sample of the forest and consequently an estimate of the measurement required which, on an average, will be the same as the true value: the estimate is *unbiased*. On the other hand, if the investigator is permitted to modify the positions of sampling units according to his personal inclination or convenience, a subjective element is introduced which may give rise to serious bias.

Even the simplest objective sampling schemes are liable to be a little inconvenient in their operation at the edge of a stand. The sampling, whether random or systematic, will generally involve a rule for the selection of the centre of every sampling unit, and, in order to ensure adequate representation of all parts of the stand, a unit must be measured for every centre having any part of its unit within the stand. A centre near to the boundary may correspond to a unit overlapping the boundary, and even a centre which is itself a short distance outside the stand may have part of its unit within the stand; omission of these units would result in under-representation of trees near the boundary in the sample, and therefore possibly lead to biased estimation. If, for example, the sampling unit is a circle of radius R, the whole sample must be derived from all circles determined according to the rules whose centres lie either within the stand or in a strip of country of width R surrounding the stand. Of course, estimates of quantities such as number or volume of trees per acre are based only on those units or parts of units which lie within the stand.

For a single large forest the inconvenience of occasionally having sampling units with centres outside the forest, and consequently of having a sample which consists of many complete units together with a few parts of units, may not be

[1] Work done in the Department of Design and Analysis of Scientific Experiment during the tenure of a Research Scholarship in Statistics awarded by the Ministry of Agriculture and Fisheries.

great. In an extensive survey of many small stands (such as would be required in an assessment of timber resources in England), however, edge areas might form an appreciable proportion of the whole acreage sampled. Both the difficulty and the cost of the survey might be much reduced if, without seriously biasing the final estimates, the sampling rules could be so modified as to require only units of standard size falling completely inside the stands. Mr. M. V. Laurie, Chief Research Officer of the Forestry Commission, has recently suggested an ingenious modification of this kind; the purpose of this paper is to examine the conditions under which bias in 'Laurie sampling' will be minimal, and to suggest how these may be fulfilled in practice.

Trees at the edge of a stand will benefit from easier access to light and root-space, an effect which will be more marked in old stands than in young. As will be apparent from the description of the procedure in Section 2, the precise conditions for freedom from bias must depend upon the nature of 'edge-effects' on the growth of trees. No exact mathematical specification of the trend from the boundary to the interior of a stand is possible, for collection of the data from which it might be assessed would be more expensive than any reasonable sampling of the stand, but, if the conditions for freedom from bias are not unduly sensitive to variations in the form of the trend, no great harm should result from using a rough approximation. Of course, a theoretical examination of the problem for a stand of irregular shape is quite impracticable, and the discussion that follows necessarily relates to an idealized situation.

2. SAMPLING PROCEDURES.

Two types of sampling units will be considered here: a square of side $2R$, whose sides are parallel to the boundaries of the stand, and a circle of radius R. For the square the stand must be assumed to have a rectangular boundary if the results are to be exactly applicable, though small irregularities should cause little disturbance. The measurement R is usually small relative to the dimensions of a stand; for example, in the inquiry that led to this investigation the sampling unit was a circle of radius 37 feet 3 inches, an area of 0·1 acre. Either type of unit is completely fixed in position by statement of its centre, and therefore, apart from modifications introduced by the Laurie sampling scheme, the rules for sampling need consist only of rules for determining a set of centres of sampling units.

(A) *Standard Sampling.*

As explained in Section 1, if bias is to be avoided the permissible positions for centres of units must consist of the whole of the stand together with a strip of width R surrounding the stand. Within this area are required a number of centres appropriate to the intensity of sampling that is to be used; the number must be a little greater than the number of units whose total area is equal to the size of sample wanted from the stand, as some units may overlap the boundary.

The centres might be selected independently of one another and entirely at random within the permissible area. Alternatively, they might be arranged in a

systematic pattern as, for example, at the corners of a square grid superimposed on the stand and the surrounding strip. (In a systematic arrangement of centres, the position of one determines the positions of all others; in order to avoid bias, the first centre should be selected at random.) The relative merits of the random and systematic arrangements have been discussed elsewhere (1, 2). All centres within a distance of R on either side of the boundary give units which overlap the boundary. The sample then consists of all units completely within the stand and all parts of units lying inside the stand; an estimate of volume per acre, for example, would be based upon the total volume of timber on the sample regarded as yielded by the total area of units and parts of units. In a survey of small stands an appreciable number of units may overlap the boundaries; the necessity of measuring the areas inside the stands will add to the labour of the field work, and the unequal sampling of different stands will add to the labour of analysing the data.

(B) *Laurie Sampling.*

The scheme proposed by Mr. Laurie requires in the first place the determination of centres as for the standard sampling, except that only centres inside the stand need be taken. Every centre will give rise to a complete unit, either standard or modified, entirely within the stand, so that choice of the number of centres amounts to choice of the exact total area of sample to be taken from a stand.

For a centre whose distance from the boundary exceeds R, the unit is taken, in the usual manner, as a circle or square with that centre. For a centre whose distance from the boundary is less than R but greater than d (where d is yet to be defined), the unit is moved until its centre is R from the boundary, the line joining the original centre and the new one being perpendicular to the boundary; the unit thus touches the boundary. For a centre whose distance from the boundary is less than d, the unit is modified to two half-units whose centres are on the boundary at distances R on either side of a perpendicular from the original centre to the boundary; the sampling unit thus consists of either a rectangle of length $4R$ and breadth R, or two semicircles of radius R which just touch. The three possibilities are illustrated in Fig. 1. It is assumed that the stand has a total width greater than $2R$, and is sufficiently large for corners to be of negligible importance: that is to say, the boundary is regarded as consisting of a series of straight portions sufficiently long for there to be a negligibly small chance that the random selection of a centre will give a point within a distance R of two edges.

The *critical distance*, d, is at the choice of the investigator. If he can specify the nature of the trend which represents the edge-effects, he may be able to determine a value for d such that the Laurie sampling method will on an average give the same result as the standard. In Section 3, d is evaluated for various alternative forms of trend, and in Section 4 the magnitude of the bias that may result from use of the wrong value of d is discussed. The formulae required are complicated and, since the trends investigated are only simple mathematical models of a complex natural phenomenon, probably of no great interest in themselves; nevertheless it seems desirable to place them on permanent record.

The reader should not allow himself to be intimidated by the formulae, as the diagrams and tables contain all that is most important to the argument!

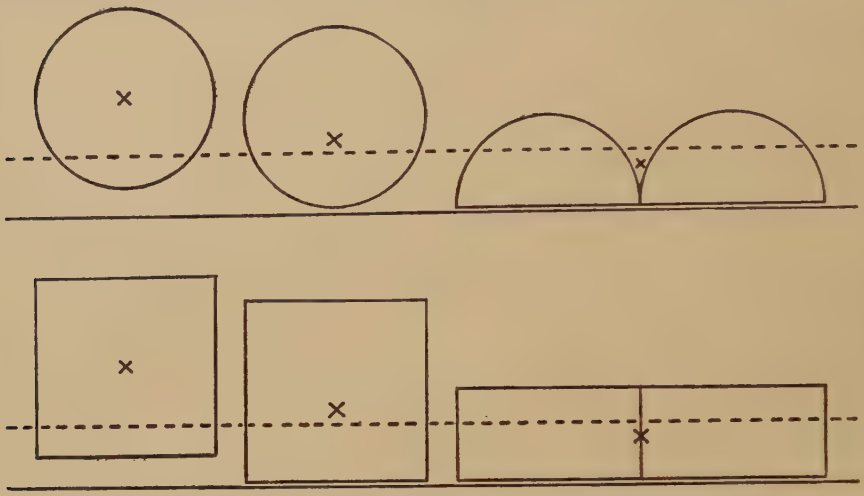

FIG. 1. The Laurie sampling scheme for square or circular sampling units.

× = Position of centre of unit, as originally selected. The full line represents the boundary of the stand, the dotted line is drawn at the critical distance, *d* (see Section 3), and units are drawn for three alternative centres.

3. THE CRITICAL DISTANCE IN LAURIE SAMPLING.

It will be assumed that a quantity described for brevity as the *yield* of a stand is to be estimated. This yield might be the total volume of timber of all or specified species, the total number of trees, or any other quantity whose total for the stand is required. In the central regions of the stand the yield per acre will be unaffected by the distance from the boundary, but in a marginal strip, of width *b*, say, the yield will be influenced by edge-effects.

'On the outside edge of a forest, trees tend to be larger and more numerous than inside owing to the greater available crown and root space, and also because foresters tend to thin the edges less heavily than the interior of a stand. On the other hand, edge trees tend to be coarser and of less good shape than the trees further in, so that the measurable volume of timber may be either more or less, depending on the criterion of measurement that is adopted. On forest edges exposed to the prevailing wind, or where an older stand adjoins, there may be an appreciable negative edge-effect.' (Laurie, private communication.)

Three different models have been tried as representative of the trend from the boundary across the marginal strip, and the effects of form of trend and value of *b* on the critical distance have been examined. The three trend models are:

(i) *Discontinuous.* The average value of the yield to be estimated is increased (or decreased) by a constant amount over the whole of a marginal strip of width *b*. Of course the yield will vary from point to point in this strip, just as it varies in the central regions, but the average edge-effect is assumed to be uniform over the strip of width *b* and thereafter to disappear.

(ii) *Linear.* The average value of the yield is assumed to decrease (or increase) uniformly across the marginal strip until a distance b from the boundary is reached; thereafter the edge-effect disappears. Again there will be variability

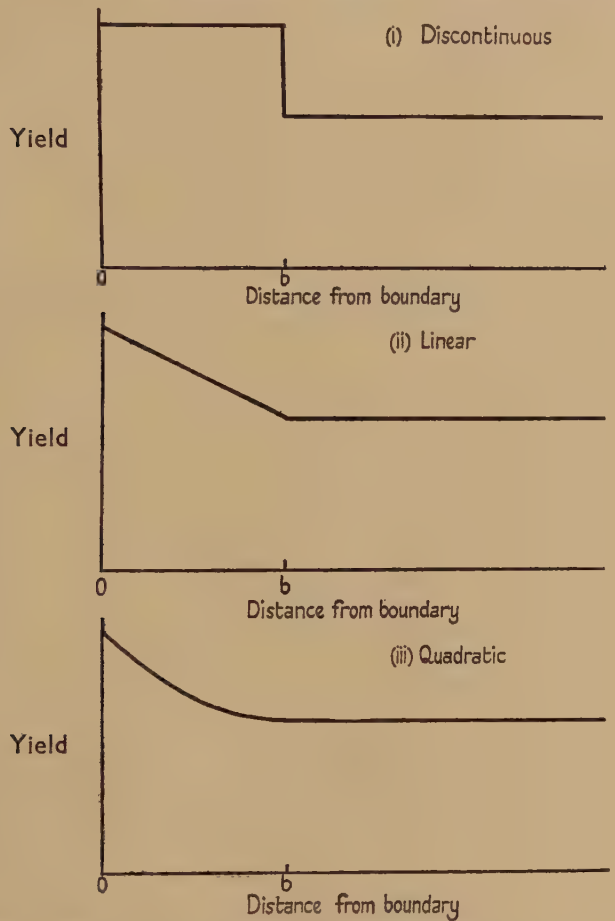

FIG. 2. Three types of trend used to represent edge-effects. (b = width of the marginal strip of forest affected by edge-effects.)

even at a fixed distance from the boundary. The effect at a distance $\frac{1}{2}b$ from the boundary will be equal to the average effect over the marginal strip.

(iii) *Quadratic.* The average value of the yield is assumed to decrease (or increase) across the marginal strip in a manner that may be represented by a parabolic curve; the parabola is taken to be horizontal at a distance b, and thereafter the edge-effect disappears. Thus the edge-effect decreases rapidly near the edge, and more slowly farther inside the forest. The average effect is found at about $0{\cdot}42b$ from the boundary.

The three types of trend are illustrated in Fig. 2. In reality, of course, both b and the form of trend are likely to vary from one part of the boundary of a stand

to another, but that for the moment must be ignored. The discontinuous trend is scarcely likely to be found in nature, but it is included as an extreme example and because it is mathematically the simplest. The linear and quadratic trends are much more reasonable representations of the edge-effects occurring for a yield such as timber volume.

For any one of the trends, and for either type of sampling unit, the average yields per acre expected with Standard sampling and with Laurie sampling can be written down. Standard sampling is unbiased, and therefore multiplication of a yield per acre determined from a Standard sample by the total area of the stand gives an unbiased estimate of the total yield of the stand. Introduction of the condition that Laurie sampling shall be unbiased requires that the two average yields be equated, and the result is a simple equation for the ratio of d to R as a function of the ratio of b to R. The formulae involve much laborious integration, especially for circular sampling units, but the principle is easily understood. Only the results are stated here. They are independent of the total width of the stand, so long as that width is not less than $2R$.

The formulae are most conveniently given in terms of the ratio θ, where

$$\theta = \frac{b}{R}.$$

Three cases have to be distinguished: $0 \leqslant \theta \leqslant 1$, $1 < \theta \leqslant 2$, and $2 < \theta$. The results for a square sampling unit are then:

(i) *Discontinuous trend*:

$$\frac{d}{R} = 1 - \tfrac{1}{2}\theta \qquad \text{when} \quad 0 \leqslant \theta \leqslant 1, \tag{1}$$

$$\frac{d}{R} = \tfrac{1}{2}\theta \qquad \text{when} \quad 1 < \theta \leqslant 2, \tag{2}$$

and d/R is indeterminate (that is to say, any value will satisfy the conditions) when $2 < \theta$.

(ii) *Linear trend*:

$$\frac{d}{R} = 1 - \tfrac{1}{3}\theta \qquad \text{when} \quad 0 \leqslant \theta \leqslant 1, \tag{3}$$

$$\frac{d}{R} = \frac{\theta^2(3-\theta)}{-6+12\theta-3\theta^2} \qquad \text{when} \quad 1 < \theta \leqslant 2, \tag{4}$$

and

$$\frac{d}{R} = \frac{2}{3} \qquad \text{when} \quad 2 < \theta. \tag{5}$$

(iii) *Quadratic trend*:

$$\frac{d}{R} = 1 - \tfrac{1}{4}\theta \qquad \text{when} \quad 0 \leqslant \theta \leqslant 1, \tag{6}$$

$$\frac{d}{R} = \frac{\theta^3(4-\theta)}{8-24\theta+24\theta^2-4\theta^3} \qquad \text{when} \quad 1 < \theta \leqslant 2, \tag{7}$$

and

$$\frac{d}{R} = \frac{2}{3} \qquad \text{when} \quad 2 < \theta. \tag{8}$$

The corresponding, but much more complicated, formulae for a circular sampling unit are:

(i) *Discontinuous trend*:

$$\frac{d}{R} = \frac{3\pi\theta - 2\theta(1+\theta)(2\theta-\theta^2)^{\frac{1}{2}} + 6\theta\sin^{-1}(1-\theta)}{-3\pi + 12\theta(1-\theta^2)^{\frac{1}{2}} + 12\sin^{-1}\theta + 6(1-\theta)(2\theta-\theta^2)^{\frac{1}{2}} + 6\sin^{-1}(1-\theta)} \qquad \text{when } 0 \leqslant \theta \leqslant 1, \quad (9)$$

$$\frac{d}{R} = \frac{3\pi\theta - 2\theta(1+\theta)(2\theta-\theta^2)^{\frac{1}{2}} - 6\theta\sin^{-1}(\theta-1)}{3\pi - 6(\theta-1)(2\theta-\theta^2)^{\frac{1}{2}} - 6\sin^{-1}(\theta-1)} \qquad \text{when } 1 < \theta \leqslant 2, \quad (10)$$

and again d/R is indeterminate when $2 < \theta$.

(ii) *Linear trend*:

$$\frac{d}{R} = \frac{3\pi(3+4\theta^2) - 2(9+3\theta+2\theta^2+2\theta^3)(2\theta-\theta^2)^{\frac{1}{2}} - 6(3-4\theta^2)\sin^{-1}(1-\theta)}{8\{-8+3\pi(1-\theta)+4(2+\theta^2)(1-\theta^2)^{\frac{1}{2}} + \\ + 12\sin^{-1}\theta - 2(3-2\theta+\theta^2)(2\theta-\theta^2)^{\frac{1}{2}} - 6(1-\theta)\sin^{-1}(1-\theta)\}} \qquad \text{when } 0 \leqslant \theta \leqslant 1, \quad (11)$$

$$\frac{d}{R} = \frac{3\pi(3+4\theta^2) - 2(9+3\theta+2\theta^2+2\theta^3)(2\theta-\theta^2)^{\frac{1}{2}} - 6(4\theta^2-3)\sin^{-1}(\theta-1)}{8\{-8+3\pi(1+\theta) - 2(3-2\theta+\theta^2)(2\theta-\theta^2)^{\frac{1}{2}} - 6(\theta-1)\sin^{-1}(\theta-1)\}} \qquad \text{when } 1 < \theta \leqslant 2, \quad (12)$$

and

$$\frac{d}{R} = \frac{9\pi}{8(3\pi-4)} \qquad \text{when } 2 < \theta. \quad (13)$$

(iii) *Quadratic trend*:

$$\frac{d}{R} = \frac{15\pi(8-9\theta-4\theta^3) - 2(120-95\theta-29\theta^2-6\theta^3-6\theta^4)(2\theta-\theta^2)^{\frac{1}{2}} - \\ - 30(8-9\theta+4\theta^3)\sin^{-1}(1-\theta)}{15\{64\theta+3\pi(5-8\theta+4\theta^2) - 4\theta(13+2\theta^2)(1-\theta^2)^{\frac{1}{2}} - 12(1+4\theta^2)\sin^{-1}\theta - \\ - 2(15-19\theta+6\theta^2-2\theta^3)(2\theta-\theta^2)^{\frac{1}{2}} - 6(5-8\theta+4\theta^2)\sin^{-1}(1-\theta)\}} \qquad \text{when } 0 \leqslant \theta \leqslant 1, \quad (14)$$

$$\frac{d}{R} = \frac{15\pi(8-9\theta-4\theta^3) - 2(120-95\theta-29\theta^2-6\theta^3-6\theta^4)(2\theta-\theta^2)^{\frac{1}{2}} + \\ + 30(8-9\theta+4\theta^3)\sin^{-1}(\theta-1)}{15(64\theta+3\pi(3-8\theta-4\theta^2) - 2(15-19\theta+6\theta^2-2\theta^3)(2\theta-\theta^2)^{\frac{1}{2}} + \\ + 6(5-8\theta+4\theta^2)\sin^{-1}(\theta-1)\}} \qquad \text{when } 1 < \theta \leqslant 2, \quad (15)$$

and

$$\frac{d}{R} = \frac{\pi(9\theta-8)}{12\pi(2\theta-1) - 32\theta} \qquad \text{when } 2 < \theta. \quad (16)$$

A selection of values of these functions is shown in Table I, and they are illustrated in Figs. 3 and 4. It is apparent that the linear and quadratic trends require practically the same value of d/R for any particular θ; the agreement is especially close for circular sampling units, but even for the square there is no

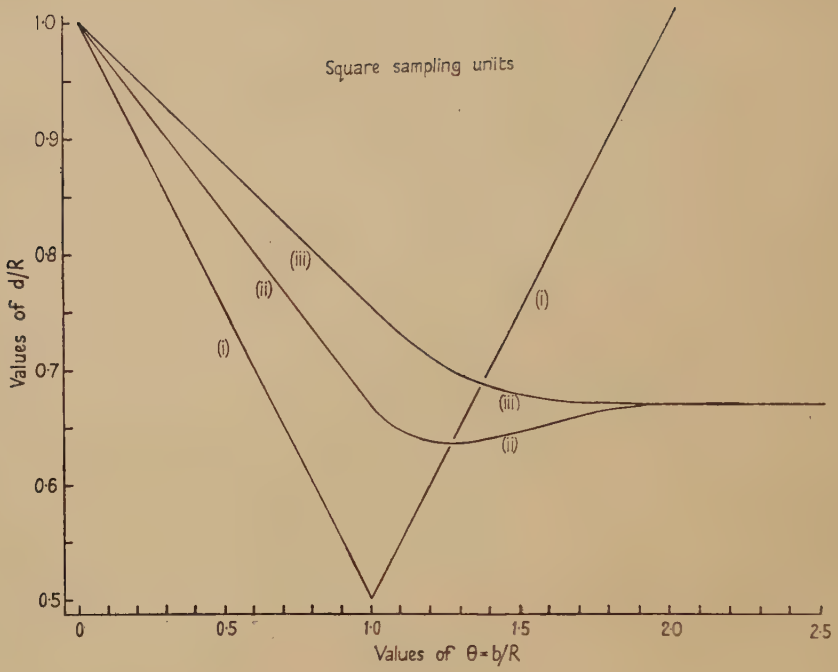

FIG. 3

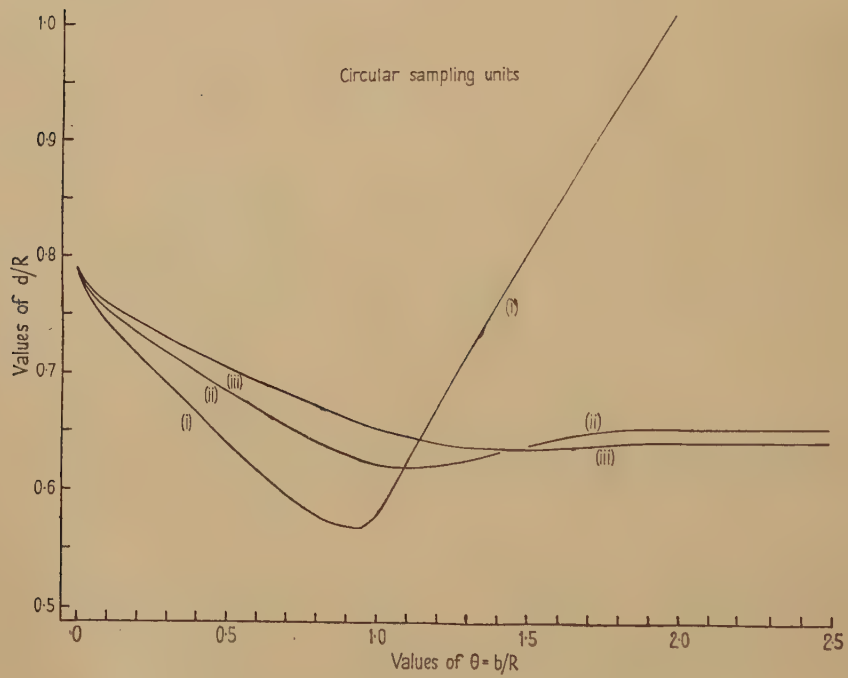

FIG. 4

FIGS. 3 and 4. The critical distance, d (see Section 3), for sampling units, expressed as a fraction of R. (R = half the length of the side of a sampling square, or the radius of a circular sampling unit.)

Curve (i): Discontinuous trend (when $\theta > 2$, any value of d/R may be used).
Curve (ii): Linear trend.
Curve (iii): Quadratic trend.

serious divergence except in the neighbourhood of $\theta = 1$. As might be expected, the discontinuous case differs substantially. When θ is greater than unity, corresponding values of d/R for the square and the circle are very similar.

TABLE I. *The Critical Distance, as a Fraction of R*

	Square unit, when trend is			*Circular unit, when trend is*		
θ	*Discontinuous*	*Linear*	*Quadratic*	*Discontinuous*	*Linear*	*Quadratic*
0·0	1·00	1·00	1·00	0·79	0·79	0·79
0·1	0·95	0·97	0·98	0·74	0·75	0·76
0·2	0·90	0·93	0·95	0·72	0·73	0·74
0·4	0·80	0·87	0·90	0·66	0·70	0·72
0·6	0·70	0·80	0·85	0·62	0·67	0·69
0·8	0·60	0·73	0·80	0·58	0·64	0·67
1·0	0·50	0·67	0·75	0·58	0·62	0·65
1·2	0·60	0·64	0·71	0·67	0·62	0·64
1·4	0·70	0·64	0·68	0·75	0·63	0·63
1·6	0·80	0·65	0·67	0·84	0·64	0·64
1·8	0·90	0·66	0·67	0·92	0·65	0·64
2·0	1·00	0·67	0·67	1·00	0·65	0·64
2·5	Indeterminate	0·67	0·67	Indeterminate	0·65	0·64
3·0	,,	0·67	0·67	,,	0·65	0·65
4·0	,,	0·67	0·67	,,	0·65	0·65

4. BIAS.

In practice, b is unknown. Laurie (private communication) suggests that, in British stands at least, it will be about one crown width and will therefore range from 8–16 feet in young crops to 40–60 feet in very old crops. A rough estimate of b might be formed from inspection of a stand and, assuming the edge-effect to be adequately represented by one of the three types of trend discussed in Section 3, the appropriate value of d could be determined. What will be the consequences of a wrong judgement in choosing the value of b?

Any bias so introduced into the estimated yield for the whole stand will depend not only on the true value of b, but on the general level of yield. Variation in the critical distance, d, can affect only the estimation of the *excess yield*, the amount by which the yield of the marginal strip of width b exceeds what it would be if there were no edge-effect and the level of yield for the central region extended to the boundary. (A stand in which the yield is reduced by proximity to the edge may be regarded, for convenience of terminology, as having a negative excess yield.) In a large stand, or in a stand for which the yield in the centre is almost as good as that at the boundary, the excess yield will play a relatively unimportant part in the total and a small bias in the estimation of the excess may have a negligible effect on the final figure for the stand. In a small stand, however, or in a stand with a strongly marked edge-effect, the excess yield may form an appreciable part of the whole, and avoidance of bias may be of greater importance.

If the marginal strip is a proportion P of the total area of the stand, and the excess yield per acre on it is a fraction e of the yield per acre in the centre (that is to say, the ratio of average yields per acre for the strip and the centre is $(1+e):1$), the excess yield contributes a fraction

$$\frac{eP}{1+eP}$$

to the average yield per acre for the whole stand. Consequently, if the estimate of excess yield is biased by a fraction B, the estimated total yield of the stand will be biased by a fraction

$$\frac{ePB}{1+eP}$$

of its true value. For a yield measurement which benefits from proximity to the edge, so that $e > 0$, this fraction is less than ePB, and, provided that eP is small, whether e be positive or negative, it will be very close to ePB. In a 10-acre square stand, for example, which is found to have an edge-effect extending about 45 feet into the stand, the strip occupies about 25 per cent. of the total area. The average volume per acre in the marginal strip is not likely to differ from that in the centre by more than 50 per cent., and therefore the bias should be at most $0{\cdot}125B$. More exactly, if the volume is known to increase at the edge, so that e is positive, the upper limit to the bias is $0{\cdot}11B$, whereas if e is known to be negative the upper limit is $0{\cdot}14B$. If d can be so chosen that B is almost certain to be less than 7 per cent.—and that, as will be shown below, should not be very difficult—the bias in estimation of the total yield of the stand will be at most 1 per cent., and may be much less if d is near the true critical distance.

The bias functions may be found by practically the same procedure as gave the critical distance formulae. The average estimates of excess yield to be expected from Standard and Laurie sampling are written down, and the difference between them is expressed as a fraction of the unbiased Standard value. The result is $B(\theta, u)$, a function of θ and u, where

$$u = \frac{d}{R}$$

is written for convenience; d is no longer the correct critical distance as given by the formulae of Section 3, but is the value which the investigator chooses after consideration of such information on b and the trend as may be available to him. The function $B(\theta, u)$ may be defined as the proportionate bias in the estimation of the excess yield if the true value of b is $R\theta$. A little rearrangement of the mathematics that led to the formulae in Section 3 then gives corresponding formulae for $B(\theta, u)$.

The formulae for a square sampling unit are:

(i) *Discontinuous trend*:

$$B(\theta, u) = \tfrac{1}{2}u + \tfrac{1}{4}(\theta - 2) \qquad \text{if } 0 \leqslant \theta \leqslant 1, \tag{17}$$

$$B(\theta, u) = u \times \left(\frac{2-\theta}{2\theta}\right) + \tfrac{1}{4}(\theta - 2) \qquad \text{if } 1 < \theta \leqslant 2, \tag{18}$$

$$B(\theta, u) = 0 \qquad \text{if } 2 < \theta. \tag{19}$$

(ii) *Linear trend*:

$$B(\theta,u)=\tfrac{1}{2}u+\frac{\theta-3}{6} \qquad \text{if } 0\leqslant\theta\leqslant 1, \tag{20}$$

$$B(\theta,u)=u\times\left(\frac{-2+4\theta-\theta^2}{2\theta^2}\right)+\frac{\theta-3}{6} \qquad \text{if } 1<\theta\leqslant 2, \tag{21}$$

$$B(\theta,u)=\frac{u}{\theta^2}-\frac{2}{3\theta^2} \qquad \text{if } 2<\theta. \tag{22}$$

(iii) *Quadratic trend*:

$$B(\theta,u)=\tfrac{1}{2}u+\frac{\theta-4}{8} \qquad \text{if } 0\leqslant\theta\leqslant 1, \tag{23}$$

$$B(\theta,u)=u\times\left(\frac{2-6\theta+6\theta^2-\theta^3}{2\theta^3}\right)+\frac{\theta-4}{8} \qquad \text{if } 1<\theta\leqslant 2, \tag{24}$$

$$B(\theta,u)=u\times\frac{3(\theta-1)}{\theta^3}-\frac{2(\theta-1)}{\theta^3} \qquad \text{if } 2<\theta. \tag{25}$$

For example, a belief that the trend was linear with

$$\frac{b}{R}=\theta=0{\cdot}6$$

would lead to a choice of 0·8 for u, by equation (3). If this value of u were used, but in fact the edge-effect extended a lesser distance into the forest, so that θ was only 0·4, equation (20) shows that a bias of −0·033 would be expected: the excess yield would be under-estimated by 3·3 per cent.[1] On the other hand, if the true θ were 1·1, equation (21) shows a bias of 0·077, or 7·7 per cent. over-estimation of the excess yield. If θ had been correctly taken as 0·6, but the trend corresponded more closely to the quadratic than to the linear type, equation (23) shows that the bias would be a 2·5 per cent. under-estimation of the excess yield. From inspection of equations (17) to (25), it may be seen that the bias is zero when u is given by the appropriate one of equations (1) to (8) with the correct θ. Figs. 5, 6, 7 show the bias as a function of θ for various choices of u.

The formulae for the circular unit naturally involve the expressions occurring in the numerator and denominator of the formulae for d/R, equations (9) to (16). In order to save repetition, the abbreviations 'Num.' and 'Denom.' will be understood as implying the numerator and denominator in the appropriate formulae. The bias formulae are then:

(i) *Discontinuous trend*:

$$B(\theta,u)=(u\times\text{Denom.}-\text{Num.})\div 6\pi\theta \qquad \text{if } 0\leqslant\theta\leqslant 1 \tag{26}$$

$$B(\theta,u)=(u\times\text{Denom.}-\text{Num.})\div 6\pi\theta \qquad \text{if } 1<\theta\leqslant 2 \tag{27}$$

$$B(\theta,u)=0 \qquad \text{if } 2<\theta. \tag{28}$$

[1] The sign of the bias is given on the assumption of a positive excess yield. If yields are reduced by the edge-effect, the words 'under-estimation' and 'over-estimation' must be interchanged.

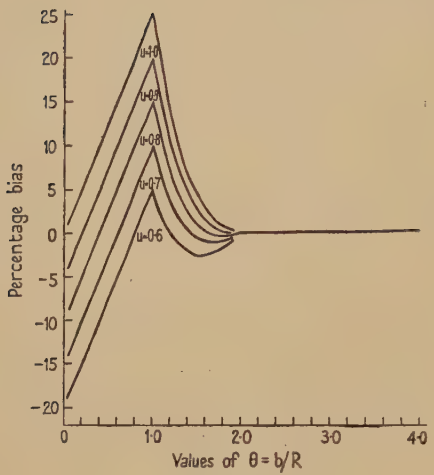

FIG. 5. Discontinuous trend.

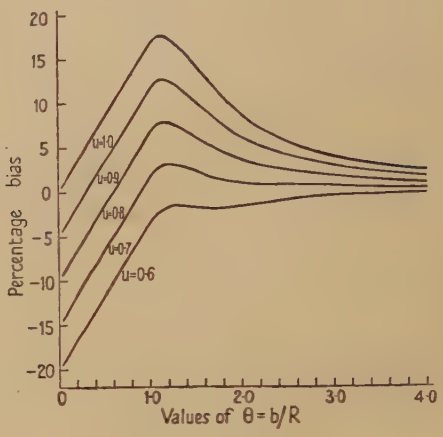

FIG. 6. Linear trend.

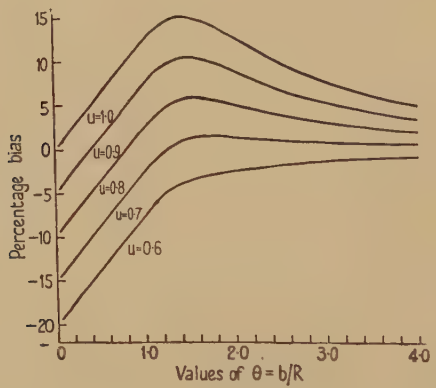

FIG. 7. Quadratic trend.

FIGS. 5–7. The percentage bias for different types of trend, evaluated for several alternative values of u.

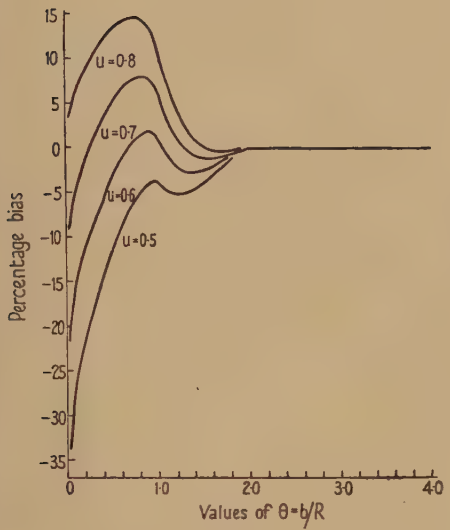

FIG. 8. Discontinuous trend.

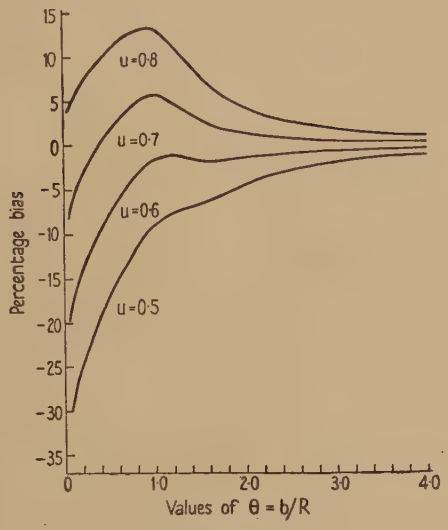

FIG. 9. Linear trend.

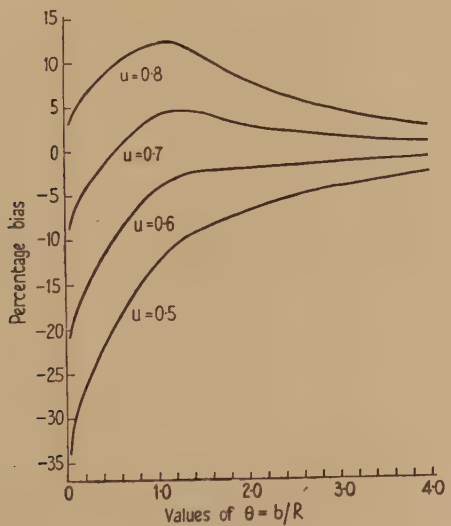

FIG. 10. Quadratic trend.

FIGS. 8–10. The percentage bias for different types of trend, evaluated for several alternative values of u.

(ii) *Linear trend*:

$$B(\theta,u) = (u\times\text{Denom.}-\text{Num.})\div 24\pi\theta^2 \quad \text{if} \quad 0\leqslant\theta\leqslant 1 \tag{29}$$

$$B(\theta,u) = (u\times\text{Denom.}-\text{Num.})\div 24\pi\theta^2 \quad \text{if} \quad 1<\theta\leqslant 2 \tag{30}$$

$$B(\theta,u) = u\times\left(\frac{6\pi-8}{3\pi\theta^2}\right)-\frac{3}{4\theta^2} \quad \text{if} \quad 2<\theta. \tag{31}$$

(iii) *Quadratic trend*:

$$B(\theta,u) = (u\times\text{Denom.}-\text{Num.})\div 120\pi\theta^3 \quad \text{if} \quad 0\leqslant\theta\leqslant 1 \tag{32}$$

$$B(\theta,u) = (u\times\text{Denom.}-\text{Num.})\div 120\pi\theta^3 \quad \text{if} \quad 1<\theta\leqslant 2 \tag{33}$$

$$B(\theta,u) = u\times\left\{\frac{3\pi(2\theta-1)-8\theta}{\pi\theta^3}\right\}-\frac{9\theta-8}{4\theta^3} \quad \text{if} \quad 2<\theta. \tag{34}$$

Thus for a circular unit a belief that the trend was linear with $\theta = 0{\cdot}6$ would entail the choice of 0·668 for u, by equation (11). If the correct value of θ was only 0·4, equation (29) shows that again there would be 3·3 per cent. under-estimation of the excess yield; if the true θ was 1·1, equation (30) shows that an over-estimation by 3·3 per cent. would be expected. If θ was 0·6, but the trend was quadratic rather than linear, equation (32) shows that use of $u = 0{\cdot}668$ would lead to 2·5 per cent. under-estimation of the true excess yield. The form of equations (26) to (34) clearly shows that the bias is zero when u is given by the appropriate one of equations (9) to (16). Figs. 8, 9, 10 show the bias as a function of θ for various choices of u.

TABLE II. *Percentage Bias in Estimation of Excess Yield*

	Square unit, with $d/R = \frac{2}{3}$ *when trend is*			*Circular unit, with* $d/R = 0{\cdot}65$, *when trend is*		
θ	*Discontinuous*	*Linear*	*Quadratic*	*Discontinuous*	*Linear*	*Quadratic*
0	−16·7	−16·7	−16·7	−17·2	−17·2	−17·2
0·1	−14·2	−15·0	−15·4	−10·1	−11·6	−12·5
0·2	−11·7	−13·3	−14·2	−6·6	−9·0	−10·3
0·4	−6·7	−10·0	−11·7	−1·2	−4·9	−6·9
0·6	−1·7	−6·7	−9·2	2·6	−1·6	−4·1
0·8	3·3	−3·3	−6·7	4·7	0·8	−1·9
1·0	8·3	0·0	−4·2	3·7	2·2	−0·2
1·2	2·2	1·5	−2·0	−0·5	1·9	0·8
1·4	−0·7	1·2	−0·7	−1·8	1·0	1·0
1·6	−1·7	0·6	−0·2	−1·7	0·4	0·9
1·8	−1·3	0·2	0·0	−0·8	0·0	0·7
2·0	0·0	0·0	0·0	0·0	0·0	0·5
2·5	0·0	0·0	0·0	0·0	0·0	0·2
3·0	0·0	0·0	0·0	0·0	0·0	0·1
4·0	0·0	0·0	0·0	0·0	0·0	0·0

Table I suggests that, unless θ is small and except possibly for the discontinuous trend, a value of u about $\frac{2}{3}$ ought to be fairly successful in eliminating bias. More exactly, $u = \frac{2}{3}$ for square units and $u = 0{\cdot}65$ for circular units seem worth further study. Table II shows the bias functions evaluated at different levels of θ for these choices of u. Provided that θ exceeds 0·5, the bias is less than 10 per cent. for any of the three trends with either sampling unit, and is almost always less than 5 per cent.

5. PRECISION OF THE ESTIMATE OF YIELD.

Earlier sections of this paper have been concerned with the problem of minimizing or eliminating bias in sampling. A procedure that has a bias of 1 per cent., if applied repeatedly, will give results that on an average differ from the true value by 1 per cent. Any single estimate of yield, however, is subject to the usual hazards of chance variation in the material: if based on a small sample of a variable stand, it may be perhaps 20 per cent. too great or 25 per cent. too small. Laurie's modification of the Standard sampling procedure has the sole object of simplifying sampling practice, and the choice of critical distance is to be made in such a way that bias is negligible. There is no reason to suppose that the precision of estimation will be appreciably altered by this modification, and certainly the emphasis in this paper on the reduction of *bias* to a negligible amount must not be regarded as a suggestion that Laurie sampling is more *precise* than Standard.

The distinction between bias and precision has been fully discussed elsewhere (1). In the absence of any theoretical description of the correlation in yield between adjacent trees or areas of a stand, investigation of the precision of Laurie sampling must await experimental evidence. A tendency for yields near the boundary not only to be greater but also to be more variable might make Laurie sampling less precise than the Standard. In any case, since the precision of estimation of forest yields from small samples is well known to be not very high, no special merits in respect of precision should be attributed to Laurie sampling.

6. RECOMMENDATIONS.

The Laurie sampling method has been described in Section 2 above. The investigations of Sections 3 and 4 indicate that, when the critical distance is carefully chosen, the method should not introduce any danger of serious bias, though this does not imply that a sample so taken will necessarily give a very precise estimate.

The bias in the estimation of the excess yield is likely to be greatest when the marginal strip over which the edge-effects are operative is narrow relative to the dimensions of the sampling unit, for small errors in the judgement of the best critical distance then have most effect on the bias (Figs. 5–10 and Table II). If the width of the marginal strip exceeds $\frac{1}{2}R$, choice of a critical distance equal to $2R/3$ for a square unit or $0{\cdot}65R$ for a circle will ensure that the bias in the estimation of the excess yield is almost certainly less than 5 per cent.—at least if the trend can be represented by the linear or quadratic models described in Section 3 or by something intermediate. Unless the stand is very small, or the edge-effect

very great, the total yield will not then be biased by more than 1 per cent. For example, if an old stand, with a marginal strip width believed to be 40–60 feet, had to be sampled with a circular unit of radius 37 feet 3 inches, the ratio of b to R would be between 1·1 and 1·6, and Table II indicates that a critical distance of 24 feet 3 inches ($= 0{\cdot}65R$) should not give a bias greater than 2 per cent. of the excess yield. A young stand, however, with an edge-effect extending only 8–16 feet, would have b/R of the order of 0·2–0·4; Table I and Fig. 4 indicate that the critical distance should be increased to something like $0{\cdot}7R$ or $0{\cdot}75R$ (26 ft. 1 in.—27 ft. 11 in.), and Figs. 7–10 show that a larger bias might result from an error in the selection of the critical distance.

The danger of a large bias in the estimation of the excess yield, on account of choice of the wrong critical distance, could be avoided by reducing the size of sampling units for young stands, and for others whose edge-effects were believed not to extend far from the boundary. A recommendation that the sampling units be always small enough to ensure that b/R exceeds 0·5 might seem desirable in order to reduce bias, as well as being in accordance with the general sampling policy of preferring (in the interests of precision), so far as is practicable, many small units to a few large ones (1). In reality, however, the situation is less simple. The investigator's interest lies not in the excess yield attributable to edge-effects in the marginal strip but in the total yield of the stand. As shown in Section 4, the bias in total yield will be less than a fraction

$$\frac{ePB}{1+eP},$$

where e is the average fractional increase in yield on the marginal strip, P is the area of the strip as a fraction of the whole, and B is the fractional bias in estimation of this excess yield. If the edge-effect acts only over a narrow strip, P will be small and even a moderately large value of B may be tolerated without seriously biasing the estimate of total yield. In fact, P is approximately proportional to b, and therefore to θ; unless e for different stands is correlated with b, when P is small the bias in total yield will be roughly proportional to θB. Since θB is much less affected by variations in θ for a given u than is B itself, inaccurate knowledge of θ should not greatly prejudice the estimation of total yield, even when θ is small. The chief advantage in having a large value of θ is perhaps the simplicity of being able to use a constant fraction of R as the critical distance, without any need of distinguishing between linear and quadratic types of trend or estimating the exact θ appropriate to the stand

Under conditions approximating to those of this paper, then, it seems fair to recommend a critical distance of $2R/3$ for a square or $0{\cdot}65R$ for a circle, providing that the edge-effect extends into the stand for a distance greater than $\frac{1}{2}R$. For narrower edge-effects the critical distance should be modified according to the most appropriate of equations (3), (6), (11), and (14).

In a heterogeneous stand, the critical distance may need to be varied from one part of the boundary to another. Provided that Laurie's rules are used for every sampling unit, with the critical distance determined for that part of the stand in

which the centre of the unit falls, the validity of the results of this paper is unimpaired by variability in the extent of edge-effects.

7. SUMMARY.

In the sampling of forests for the estimation of timber volume or other measures of yield, precautions must be taken to avoid bias in the results through misrepresentation of those marginal areas where proximity to the boundary allows greater freedom for growth. Ordinarily this will require that sampling units may overlap the boundary, and special measurement and calculation will then be needed in order to make proper use of parts of units. As an alternative, units which would otherwise overlap the boundary may be modified in one of three ways: they may be rejected, replaced by two half-units just inside the stand, or moved until they are just inside the stand. The Laurie sampling scheme, described in this paper, is designed to avoid bias in yield estimation by proper choice of when each of these modifications is to be adopted.

Exact solution of the problem of how to make this choice depends upon numerical values of various properties of the edge-effects, which in practice cannot be known by the investigator. Simple mathematical models of the kind of effect that may occur have been examined, however, and the conditions for freedom from bias have been stated: the bias resulting from inexact expressions of the edge-effects has also been studied. The results depend upon the form of the edge-effects and upon the distance that they extend into the forest, but they are independent of the total width of the forest. If yield trends in a stand approximate to one or other of the models discussed, careful choice of a critical distance should enable the bias in the estimate of total yield to be reduced below one per cent. for all but the smallest stands, and to be made much smaller for large stands. Such a bias should be negligible in comparison with the sampling errors to which an estimate is subject, unless the sampling is very intensive, particularly as it will not always be in the same direction and will therefore be proportionately still smaller when averaged over many stands.

ACKNOWLEDGEMENTS.

We are indebted to Messrs. M. V. Laurie and F. C. Hummel, of H.M. Forestry Commission's Forest Research Station, Alice Holt, both for suggesting the problem of this paper and for many helpful comments on the presentation of the results.

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SPIRAL STRUCTURE AND SPIRAL GROWTH

THE DEVELOPMENT OF SPIRAL GRAIN IN CONIFERS

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INTRODUCTION.

IN an earlier paper (11) an explanation has been attempted of the spiral growth of single cells, in terms of two concepts—wall structure and elastic properties—generally considered as fundamental to the phenomenon. It has been shown that the formula developed is, at the very least, not inconsistent, quantitatively, with the data available. Now it seems very probable, as pointed out by Castle (3), that this spiral growth of single cells, a relatively rare phenomenon for which data are available as yet only for the sporangiophores of *Phycomyces*, is the elementary phenomenon lying behind most, if not all, of the more widespread manifestations of spiral growth in tissues. It is proposed, therefore, to examine here one case of spiral growth, analytically the simplest and certainly the one to which most attention has been paid, spiral grain in conifers. It will be well first to outline the salient features of spiral grain; the close parallel with spiral growth in *Phycomyces* will be obvious.

SPIRAL GRAIN IN CONIFERS.

A full account of spiral grain in conifers has been given by Champion (4), and a detailed study has been made in this Department by Misra (7), from whose papers the data used below have been drawn. By the term *spiral grain* it is implied that the tracheids in the wood, instead of lying with their lengths parallel to the length of the trunk, are inclined to this length at a common angle, the grain therefore lying along a spiral round the trunk. This spiral is reported to be usually left-handed in young trees and is apparently initiated in the second year. The twist is more intense at the base of the tree, particularly if the base becomes bulbous, though Canning (2) has drawn attention to a number of right-twisted trees where the reverse is the case—the twist being greater higher up the tree. As shown by Misra (7), in subsequent annual rings the tilt of the tracheids from the longitudinal becomes progressively greater, rapidly at first and then more slowly, until finally it reaches a more or less steady value. After some further period the tilt in later annual rings gradually decreases again, so that the tree may be finally clothed in layers of wood in which the tracheids run longitudinally and the bole appears to be straight-grained. Finally, in very old trees the tracheids may tilt in the opposite direction and lie along a right-hand spiral. Here, therefore, occurs a reversal of spiralling, resembling, even if somewhat remotely, the reversal observed in *Phycomyces*.

The various theories put forward to explain spiral grain—injury, wind effects, soil deficiencies, climatic conditions, &c.—have been ably reviewed by Champion. These, however, are inadequate as complete explanations, because spiral grain can appear in trees grown under normal conditions without special treatment and with no evidence of injury. One may conclude in general that pronounced development of twist is connected in some way with excessive growth vigour; and there are clearly two ways of attacking a problem such as this. What may be called the 'physiological' method, the one most frequently used, involves observation of trees in the field, particularly under different environmental conditions. This may yield information on the *external* factors leading to the development of spiral grain; and the successful conclusion of such an attempt might readily suggest the *internal* factors which are more directly responsible. The 'anatomical' method, on the other hand, involves careful observation of the structural features in the wood peculiar to conifers with spiral grain. This constitutes a more direct attack on the *internal* features involved and might readily indicate the corresponding *external* factors. This latter method has been used with conspicuous success by Misra (7), who has shown that the tilt of the grain at any point in an annual ring is related inversely to ring width, to the tilt of the micelles in the tracheid wall, and to the length of the tracheids. These three factors, however, are not independent. Thus the length of a tracheid determines the angle at which the micelles are laid down in its walls (Preston, 9; Preston and Wardrop, 13; Misra, 7) and the length is also usually associated in some way with ring width (Jaccard and Frey, 6; Misra, 7). It seems unfortunate, therefore, that in a later work Misra (8) has concentrated attention on only one of these factors (ring width), to the exclusion of the others, with a consequent over-emphasis on factors associated with ring width, which may be irrelevant.

It is the purpose of the present paper to try to take Misra's work one step farther in the search for the internal factors. If there is any connexion between spiral grain and spiral growth in *Phycomyces*, then cells must be sought for in the conifer which are elongating and have a wall structure similar to that assumed to obtain in the growth zone of sporangiophores; and, of course, we have such cells readily available in the fusiform initials of the cambium. These are elongated cells, approximately equal in length to the tracheids they have just produced, and the primary wall which surrounds them is wound with cellulose chains which, in *Pinus radiata* D. Don (Preston, 10), and *P. sylvestris* L. (Preston and Wardrop, 13) (the only two species known in sufficient detail), make an angle to the transverse of the order of 10°. It is proposed, therefore, to consider whether the length changes in the cambium, recorded as tracheid lengths by Misra, can account quantitatively for his figures for spiral grain.

THEORETICAL CONSIDERATIONS.

In the earlier paper (11) it was shown that if a cylindrical cell, length L, wound with fibrils making an angle α to the transverse, elongates by an amount ΔL, then provided no constraint, internal or external, is put upon the cell, one end of the

cell will rotate relative to the other about the longitudinal axis of the cell, by an angle $\Delta\phi$ given by the relation

$$\frac{\Delta\phi}{\Delta L} = \frac{\cos\alpha \sin\alpha\{1-(2n/q)\}}{a\{\cos^2\alpha+(2n/q)\sin^2\alpha\}}, \tag{1}$$

where n is the torsional rigidity and q the Young's modulus of the spirally arranged fibrils, and a the cell diameter, provided that the fibrils are circular in cross-section. If we imagine such a cell to be laid lengthways on a rough surface and suppose extension to be caused by pressure from within, then the two ends of the cell will clearly roll in such a way that the whole cell twists about a line, normal to the surface on which it is lying and passing through the geometrical centre of the cell, through an angle which may be designated ψ. This angle may be determined simply by assuming one end of the cell to be held stationary, when the other end of the cell will rotate through the whole angle $\Delta\phi$ (Fig. 1) and roll along the table through a distance $a\,\Delta\phi$. Hence it is clear that

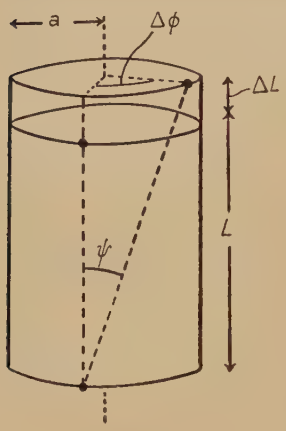

FIG. 1

$$\tan\psi = a\frac{\Delta\phi}{(L+\Delta L)}. \tag{2}$$

Hence

$$\tan\psi = \frac{\cos\alpha \sin\alpha\{1-(2n/q)\}}{\{\cos^2\alpha+(2n/q)\sin^2\alpha\}} \frac{\Delta L}{(L+\Delta L)}$$

by substituting from (1) into (2).

If now the organization of the primary wall can be considered to remain approximately constant over several annual rings (which seems, in fact, highly probable), then α, n, and q may be regarded as constants, when

$$\tan\psi = A\frac{\Delta L}{(L+\Delta L)} \tag{3}$$

where A is a constant.

This simple relationship can easily be tested against the figures given by Misra (7). Only in two cases are his figures such as to be immediately applicable to equation (3). Remembering, however, that the average length L of tracheids in any one annual ring (= cambial length) is related to the average cotangents of the angles of the micellar spirals by a relation of the type

$$L = K\cot\theta$$

(Preston, 9), then (3) may be rewritten

$$\tan\psi = A\frac{\Delta(\cot\theta)}{\cot\theta+\Delta(\cot\theta)}. \tag{4}$$

This allows one further set of data to be used.

RESULTS.

The figures against which the present theory is to be checked are, in point of fact, somewhat unsatisfactory for several reasons. First and foremost is the inevitable fact that the measurements of cell lengths are averaged over a whole zone of wood, viz. the early and late wood of any annual ring. Clearly it would be much better if a single radial file of tracheids could be picked out. Secondly, the number of length measurements used to obtain an average is rather small, and the standard error is correspondingly large, so large indeed that there is often no significant difference between one annual ring and the next! Thirdly, the theory demands that cot θ and L be determined at one and the same place, and this is certainly not true of the figures available. Nevertheless, the figures are useful in a preliminary investigation such as this is intended to be, in spite of these disabilities.

TABLE I. *Data on inclination of grain to the axis of the trunk and the angle* (θ) *of the micellar spiral in the constituent tracheids, recalculated from Misra* (7)

*Region of wood**	*Inclination of grain* ($\psi+2$)	tan ψ	cot θ			$\frac{\Delta \cot\theta}{(\cot\theta+\Delta\cot\theta)}$		
			Avg.	*Max.*	*Min.*	*Avg.*	*Max.*	*Min.*
3 E	2	..	0·710	0·737	0·662	..	..	..
3 L	7	0·079	0·878	0·918	0·845	0·193	0·253	0·130
4 E	10	0·140	1·150	1·210	1·100	0·382	0·438	0·328
4 L	12	0·176	1·230	1·260	1·190	0·421	0·459	0·378
5 E	12	0·176	1·320	1·380	1·280	0·463	0·504	0·428
5 L	12·5	0·185	1·380	1·450	1·300	0·484	0·528	0·431
6 L	13	0·195	1·746	1·850	1·650	0·591	0·630	0·555

* The number gives the annual ring; E = early wood, L = late wood.

The relevant data, calculated in terms of the equations given above, are presented in Tables I and II. It will be clear that the present data lend themselves to numerical checking only after the grain has begun to tilt, because it is naturally impossible to determine just where in the second annual ring the tilting began. Hence in Tables I and II the second annual ring is taken arbitrarily as the datum line, and the spiral grain angles (ψ in the tables) are reckoned in excess of the tilt of the wood in this ring. This adds nothing undesirable, of course. In Fig. 2 the results are pooled in one graph, where the limits of error are indicated by the lengths of the straight lines drawn parallel to the abscissa. In each case the means lie approximately along a straight line. The regression line may be calculated as

$$\tan\psi = 0{\cdot}35\,\frac{\Delta L}{(L+\Delta L)} = 0{\cdot}35\,\frac{\Delta(\cot\theta)}{\cot\theta+\Delta(\cot\theta)}.$$

It is striking that the value for A for the three samples (*two* different samples of wood) is close to 0·35 and it may be as well to examine precisely what this value may mean in terms of α, n, and q. A series of measurements made on *Pinus*

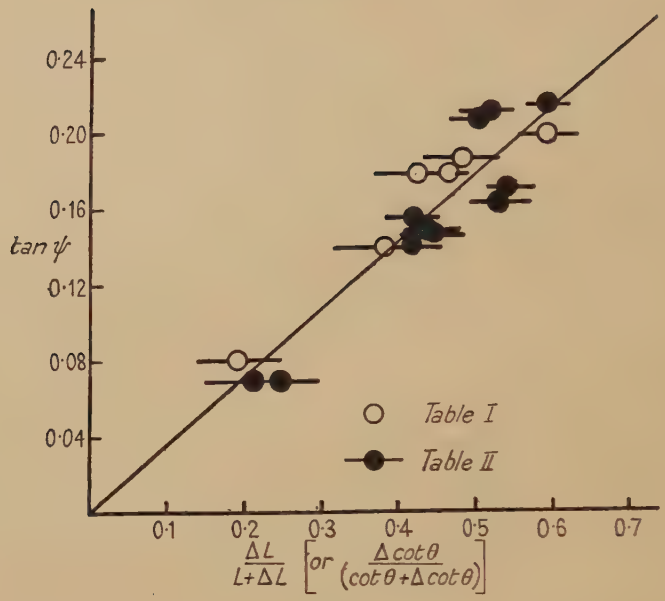

FIG. 2

TABLE II. *Data on inclination of grain to the axis of the trunk, ψ, and tracheid length, L, recalculated from Misra* (7)

*Region of wood**	tan ψ	ΔL/(L+ΔL) *Avg.*	*Min.*	*Max.*
Octant 1				
3 E–2 L	0·070	0·249	0·148	0·296
4 E–2 L	0·140	0·415	0·369	0·457
5 E–2 L	0·145	0·449	0·408	0·485
6 E–2 L	0·146	0·436	0·402	0·471
7	0·162	0·530	0·495	0·561
8	0·168	0·543	0·519	0·570
Octant 5				
3	0·070	0·216	0·158	0·269
4	0·155	0·420	0·384	0·454
5	0·177	0·453	0·415	0·487
6	0·206	0·500	0·467	0·529
7	0·209	0·516	0·482	0·546
9	0·212	0·595	0·570	0·618

* The number gives the annual ring; E = early wood, L = late wood.

longifolia Roxb. tracheids by the method used for *P. radiata* D. Don (Preston, 10) gave the value of α (primary wall) as $12° \pm 2°$.

Hence using the relation

$$A = -\frac{\sin\alpha\cos\alpha\{1-(2n/q)\}}{\cos^2\alpha+(2n/q)\sin^2\alpha},^*$$

we may calculate n/q. The average figure appears to be 1·6 but the value of n/q is very sensitive to change in α. This is considerably higher than the value found by Clayton and Pierce (5) for cotton, but that is perhaps to be expected in view of the structure of the primary wall (Preston and Wardrop, 13). Not only, therefore, do the observed values of $\tan\psi$ and $\Delta L/(L+\Delta L)$ (or the equivalent

$$\Delta(\cot\theta)/(\cot\theta+\Delta\cot\theta))$$

fall approximately on a straight line, but the slope of the line is not inconsistent with the organization of the primary wall, so far as it is known.

DISCUSSION.

It is not proposed at the moment to carry the present inquiry farther than pointing out the possibility of a connexion between the twisting of an elongating spiral and the direction of spiral grain. Until, in fact, the theory has been tested rigorously by much more numerous and more accurate data, there is little point in going farther. However, there are one or two points which it is proper to take up at this time. It seems inevitable that the cambial initials will tend to twist about their longitudinal axis as they elongate; whether they can actually do so depends on a number of conditions. It might be inquired, for instance, if the anatomy of the cambium and its surrounding tissues is such as to allow this twisting; and why so comparatively few trees are reported as showing twist at all. As regards this latter point it is pertinent to inquire within what limits the grain of a tree could be called 'straight'. In point of fact the writer had occasion, a few years ago, in collaboration with the late J. H. Priestley, to examine a number of 10-year-old saplings of *Pinus sylvestris* L. in a typical healthy plantation, and in every case the grain was markedly, but not excessively, twisted. This could not be detected until a foot or two of bark had been removed, and one wonders how many saplings really have straight grain. A certain degree of spiral grain may well be more common than is supposed, though only in special cases, or under special conditions, does the spiral become so excessive as to be easily observable.

If cambial initials are to twist, it follows that either slip must occur between cells, or tissues must be distorted, or both. Displacements can occur only if the torque which the initial can apply around its longitudinal axis is sufficiently high, and it is therefore to be noted that this torque increases as the turgor of the cell

* The minus sign is inserted in the formula to imply that the spiral *uncoils* as it elongates. Otherwise (if the spiral is assumed to *coil up*) n/q is negative.

increases, and as α increases, i.e. as the spiral becomes steeper. It is equally possible that twisting may result from a decreased resistance to torque, as, for instance, from a change in the consistency of the middle lamella, or any other factor associated with tissue rigidity.

With regard to the more anatomical considerations it may be pointed out that, commonly, the middle lamella in meristematic tissue consists of pectin or some related jelly-like substance, whereas in mature tissues this material is transformed into the calcium or some other firm derivative, and in the case of wood is also hardened by lignification. Hence we should expect the 'rolling' of cells, consequent upon the twist demanded by this present hypothesis, to occur most readily on the xylem. In view of the regular longitudinal-tangential division of the cambium, implying, as it does, that several related cells in a radial file are enclosed for a period in a common mother-cell wall, it is a little difficult at first sight to visualize this rolling process in operation. It must be remembered, however, that the movement in any one cell is very small. The maximum twist given by Misra (13°), for instance, occurred at a distance of 16 mm. from the centre of the stem. Even if we take the average radial diameter of a cell as high as 30 μ, then only after about 530 tracheids has this tilt been reached. This gives the average angle moved through by any one cambial cell, between two successive divisions, as 0·02°. Taking the average tracheid length at 3,000 μ, this implies a movement of each end of the cell, if the centre is considered fixed, of only 0·6 μ, or about 0·5 per cent. of the girth of the tracheid. Again, if we assume a growing period of as little as 2 months per year, then these 530 tracheids are laid down in a total growing time of at least 9 months, or about 270 days, i.e. one cell is laid down every 12 hours. Hence the twist occurs more slowly than 1·2 μ in 12 hours, or 0·1 μ per hour.*

The satisfactory agreement with theory in early annual rings should not be allowed, however, to mask the failure of the tilt to increase in the later annual rings. This recalls the gradual cessation of right-hand spiralling in *Phycomyces* and might be susceptible of a similar explanation (Preston, 11). If this were so, then the gradual straightening out in later years, and finally the reversal of spiralling, might also be explained. However, it is equally possible that the tilting of tracheids is halted by some other factor, perhaps purely anatomical; the rays, for instance, could obviously interfere.

Finally, perhaps it may be pointed out that the present theory offers satisfactory explanations for some otherwise curious correlations quoted by Misra (7). As tracheid (and therefore cambial initial) length is connected with ring width in such a way that narrower rings have longer tracheids (Baranetsky, 1; Jaccard and Frey, 6; Misra, 7), we should expect a rough inverse correlation of twist with ring width; for it would appear that narrower rings are associated with greater cell elongation. It is possible, therefore, that Misra, in following up the connexion with ring width, is being led into an issue of secondary importance.

* More recently the writer has found, in collaboration with A. B. Wardrop, that in *Pinus sylvestris* L. one tracheid is laid down per cambial initial in about 48 hours. If this proved to be true for *Pinus longifolia* Roxb., then the time rate of twist would be reduced to 0·025 μ per hour.

SUMMARY.

In the present paper an attempt is made to carry the explanation of spiral grain in conifers a little farther than has hitherto proved possible. If an elongated cell, covered by a spirally organized cell wall, is increasing in length, then, provided no external agency intervenes, the cell will twist around its longitudinal axis through an angle calculable in terms of the pitch of the spiral and the elastic constants of the spiral winding. It follows that if the cell is laid against a rough surface it will tend to 'roll' around a line normal to the surface and passing through the geometrical centre of the cell. It is suggested that this is what happens in the cambium of conifers showing spiral grain, and it is shown that the theory gives a relation between the angle of tilt of the grain and the length changes in the cambium, of the type observed by Misra. The theoretical line can be fitted to the observed values by the assumption of a value of n/q which is not unreasonable in view of the structure of cambial cell walls. Some consideration is given to the factors which may lead, in terms of this theory, to the development of excessive spiral grain.

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LETTERS TO THE EDITOR

From MR. H. FAIRFIELD SMITH, *The Rubber Institute of Malaya*, P.O. Box 150, Kuala Lumpur, Malaya.

Sir, 21.3.1949.

Replicated Experiments

Reference correspondence in *Forestry*, Vol. xxii, No. 1, pp. 113–17, on replicated thinning experiments, the following comments, based on experience of experiments on plantation rubber, may be of interest.

The efficiency of a Latin square depends on a balance between reduction in error variance and the reduced number of degrees of freedom for estimating that variance. Its reputation for field experiments has been gained in work with agricultural crops. These are usually planted on more or less level fields where, before planting, there is no visible criterion of variation in fertility, where propinquity of plots has been found empirically to be advisable, and the Latin square is often an ensurance against wrong orientation. Only occasionally do we find an area for rubber planting (and, I expect, for forestry) similar to an agricultural field. Usually the land is hilly and intersected with streams and swamp areas. To try to impose a 'square' arrangement of plots usually leads to odd plots being situated on rock outcrops or in swamps, thereby causing differences which are not averaged out by the rows and columns. It is therefore not a suitable arrangement for forestry experiments, not just because of the loss of degrees of freedom, but because on hilly land it does not serve its purpose in exchange for that loss. On a plain it may be as useful as in agriculture. An effective alternative is so simple that it seems strange it has been so often overlooked. Under forestry conditions there are frequently marked features by which similarity of areas can be assessed: contours, stretches of alluvial soil, &c. For effective reduction of heterogeneity one has merely to pick groups of plots which appear similar on any criterion independent of the treatments, and use these groups as blocks for a randomized block design. The units of each group may be contiguous but need not necessarily be so. The important thing about a block is that all units within any one such should be as similar as possible. Contiguity of units, although usually beneficial, is incidental and can be abandoned without hesitation if any better criterion of similarity is available. For example, by grouping as blocks plots on hill-tops, on slopes with similar aspect, or on gully bottoms, &c., it has been found fairly easy to obtain standard errors for girths per single acre or half-acre plot about 2 per cent. of the mean, and sometimes lower.

My second comment refers to Mr. Wicht's proposal to omit replication of a graded series of treatments, computing an estimate of error from deviations from regression. Mr. Finney has pointed out that without an unambiguous estimate of error one has difficulty in knowing when the curve being fitted is suitable to describe all the systematic variation. The point is important if one is studying the form of curve presented by the response. But even if one is not concerned with the form of curve, it is still most effective to concentrate observations at only a few levels of the independent variable, the number and position of points to be observed depending on the parameters to be estimated. This does not seem to be generally appreciated. In agricultural and forestry experiments, where treatments usually cover only a small range, straddling economic levels, almost any curve with the required flexibility will serve for interpolation within the limits of experimental uncertainty. Usually a quadratic is adopted for convenience of computation, and this can

be evaluated most accurately by concentrating the observations at only three points, at the extremes and centre.

The following table shows the efficiencies of fitting a quadratic to data in the range $x = 0$ to 6 with observations distributed as follows:

I: $n/3$ observations at each of 3 levels $x = 0, 3, 6$.
II: $n/4$ „ „ „ „ 4 „ $x = 0, 2, 4, 6$.
III: $n/8$ „ „ „ „ 8 „ $x = 0, 6/7, \ldots, 5\frac{1}{7}, 6$.

The table gives the error variance of estimates of the regression coefficients B and C in the orthogonal binomial

$$y = A+B\xi_1+C\xi_2.$$

The variance of $A = \bar{y}$, is, of course, σ^2/n for all distributions; B gives the slope of the curve at the point where it can be estimated most accurately. The variance of the coefficients of the regression in the form

$$y = y_0+b_0 x+cx^2$$

are also given, because the starting-point (y_0) and initial slope (b_0) for very small doses of the treatment are often of special interest ($c = C$). The table also shows variances of estimates of the dependent variate (y) at two other points, namely, at the mean value of the independent variate ($\bar{x}$) and at the point (x_m) where $V(y)$ is minimum. From the orthogonal binomial for equally spaced values of x it may be deduced that

$$nV(y_x)/\sigma^2 = 1+(x-\bar{x})^2/\mu_2+\{(x-\bar{x})^2-\mu_2\}^2/(\mu_4-\mu_2^2),$$

where σ^2 is the error variance of a single observation (plot), and μ_2 and μ_4 are the second and fourth moments of the distribution of x about its mean. This has a single minimum at $x = \bar{x}$, when the distribution of x is leptokurtic, i.e. when $\beta_2 = \mu_4/\mu_2^2 > 3$. But when the distribution of x is platykurtic, $\beta_2 < 3$, as is usually the condition in experimental work with deliberately spaced values, there is a maximum at $x = \bar{x}$, and two minima at

$$x_m = \bar{x} \pm \{\tfrac{1}{2}(3-\beta_2)\mu_2\}^{\frac{1}{2}}.$$

The table shows that distributions II and III are only about 88 and 63 per cent. as efficient as I for estimating the regression. Correspondingly I gives reasonable accuracy in estimating y over a wider range than do II and III, although II and III give higher accuracy (for estimating y) near the middle of the range where they have more observations. However, even this advantage disappears if we are concerned only with differences between levels. For the difference between estimates of y at any two given levels, x_1 and x_2,

$$\frac{n}{\sigma_2} V(y_1-y_2) = \frac{\Delta^2}{\mu_2}+\frac{\{2\Delta(x_i-\bar{x})\}^2}{\mu_4-\mu_2^2} = \Delta^2 V(B)+\{2\Delta(x_i-\bar{x})\}^2 V(C),$$

where $\Delta = x_1-x_2$, $x_1 = \frac{1}{2}(x_1+x_2)$; and these being fixed, $V(y_1-y_2)$ obviously depends only on $V(B)$ and $V(C)$, which are both least for distribution I.

Admittedly there is risk of some bias in the estimates of interpolated values if the fitted curve fails to follow the true curve exactly, and such bias will not be included in the estimate of error variance for case I. But this will seldom be detectable at the degree of accuracy realizable in field experiments. If an estimate of the slope at one particular point, say near y_0, is specially important, it may seem advisable to have extra observations at smaller intervals to check goodness of fit of the fitted curve in that neighbourhood. But if intervals are unequal, computing labour will be greatly increased, since orthogonal

polynomial technique is not then convenient, and unless the experiment is exceptionally accurate the extra labour will not usually be repaid.

Case	*Error variance* × n/σ^2 *for* B	C	b_0	y_0	y_3	y_m	$x_m = \bar{x} \pm$
I	0·166̇	0·055̇	2·166̇	3·0	3·0	1·875	2·121
II	0·2	0·0625	2·45	3·8	2·5625	1·84	1·844
III	0·2̇5̇9̇	0·08822	3·43̇5̇1̇8̇	5·666̇	2·3125	1·810	1·543
	Relative amounts of information as per cent. of I						
II	83	89	88	79	117	102	..
III	64	63	63	53	130	104	..

Yours faithfully,

H. Fairfield Smith

(The Rubber Research Institute of Malaya,
Kuala Lumpur.)

REVIEWS

Home Timber Production (1939–1945). By Russell Meiggs. Crosby Lockwood & Son, Ltd., London, 1949. pp. 277 and 24 photographs. Price 15s.

Review by H. M. Steven

THIS country's war effort was nourished by its whole resources, human and material. This kaleidoscopic effort can never be completely documented, hence the forest and timber industries are indeed to be congratulated in having their war-time achievements recorded and by such an able historian as Mr. Russell Meiggs. He came from the cloistered calm of that academic holy of holies, Balliol College, and from the Elysian fields of Ancient History to join that motley throng—in no derogatory sense—of timber men, landowners, and civil servants, with only an occasional academic bird, who were responsible for the organization of the war-time timber supplies; he was Chief Labour Officer of the Timber Production Department from 1941 until the end of the war. The reviewer's first meeting with him was on Scottish Deeside, after his journey over Cairn o' mount on a dirty night. One of his companions told me that he had made the swirling mists even more eerie by incantations of Greek poetry. Thus the author came fresh to a new scene and undreamt of problems. This objective approach is one of the distinctive qualities of the book. Lest any potential reader should think that Balliol dons only write rarefied academic treatises, let me hasten to add that this book is a model of simple and lucid prose and is eminently readable. The principal reason, however, why all who are interested in forestry, professionally or otherwise, should read this book is that it records an important period in the forest history of this country which will long influence its forest policy.

Timber is a raw material which is even more vital to war effort than to peace-time economy. Moreover, it is a raw material which we import to the tune of 96 per cent. in peace-time, and it is the bulkiest of all our import cargoes. Hence it should be produced at home to the maximum extent when shipping is scarce. No special reserves had been accumulated in September 1939; the reserves of standing timber were substantially less than in 1914; and the home timber trade, always relatively small, was only recovering from the depression of the 1930's, which had affected adversely the size of its labour force and its equipment. The task of the rapid expansion of home timber supplies was, therefore, a formidable one, and scarcely less the smooth integration of such supplies with import programmes. Nevertheless, in spite of many difficulties and mistakes, 18½ million tons of timber were obtained from home sources during the period 1939–45, out of the total national requirement of 31 million tons. Although there were critical times, particularly between 1941 and until the Battle of the Atlantic was finally won in 1943, the needs of the services, the mines, and the railways were met at all times.

This book tells the story of how this was accomplished. The organization of the work, the resources of raw material, production policy, trade and departmental production, all the varied kinds of labour used, and plant and machinery are discussed, where appropriate, with brief sketches of the historical background. Lack of space forbids anything more than a brief statement of the major conclusions, although this book is a mine of interest and information.

The heavy sacrifice of private woodland owners is rightly stressed. No other belligerent had to sacrifice anything approaching such a large proportion of its growing stock of timber,

and as most of the Forestry Commission woods had not reached utilizable size, the burden fell on private woodlands. Only professional foresters can fully appreciate what it means in so many ways, biologically, silviculturally, and economically, to lose the major part of one's growing stock, mature and immature; and this should never be forgotten when considering and applying the Government post-war plans of woodland reconstruction.

The exhaustion of utilizable timber threatens doom to the home timber trade whose great efforts are described. This is perhaps the greatest tragedy of the destruction of our woodlands, because, apart from personal reasons, forestry cannot flourish in any country unless there is a timber trade, enterprising, resourceful, and well equipped. Every effort must be made to ensure that accumulated skills and knowledge, alike of management and men, are conserved and developed. That calls for sympathetic help from the Government and a realistic approach by the trade, and particularly the development of co-operation and not struggle between its members. The only silver lining here is that there is some evidence of the drawing together of growers of timber and the timber trade, which should increase if the trade can undertake a part of the work of the rehabilitation of our woodlands.

Labour supply was the major problem, and the author gives an excellent account of the many kinds of labour engaged in the war-time timber effort, home and overseas, military and civilian, male and female. The chapters dealing with this subject are perhaps the most interesting part of the book.

Sir Gerald Lenanton, who was Director of the Ministry of Supply Home Timber Production Department from 1941 to 1946, contributes a Foreword. The photographic illustrations are both well chosen and good. An appendix contains most of the production and labour data, and there are extensive personnel lists.

Forestry in Germany: Present and Prospective. By C. A. Schenck. Newsprint Service Bureau Inc., New York, 1948.

Review by G. B. Ryle

THIS pamphlet of 42 pages is a concentrated plea for the preservation at all costs of German forests from over-cutting to meet the urgent needs of western European recovery. The case is comprehensively argued but is spoiled even for the lay reader by ebullient hyperbole on almost every page. It is correctly stated that the rape of German forests began under the Hitler régime, with Reichs-forstmeister Göring as the nigger in the woodpile. It is hardly correct, however, to imply that the Allied Military Governments continued the same policy, because the post-war needs for timber, both within and beyond the German boundaries, were essentially for very different reasons; they were an aftermath of the Nazi bid for domination.

Schenck takes an untenably gloomy view of the future of German forestry. The excessive post-war fellings are 'destroying this foundation of all true forestry for ever and ever'. Speaking of the exposure of the forest soil by large clear fellings, he states: 'What is once spoiled remains forever spoiled.' Less than 40 years ago German forestry was on top of the world 'and indeed had mastered its problems'. To-day 'it is crestfallen, it is on the downgrade, it is in despair and it has lost its leadership'. Whereas it is true that German forestry has suffered and continues to suffer desperately, there is now no sign of defeatism amongst German foresters, who are generally facing the inevitable post-war frustrations with courage: the change during the past two years has been notable.

The possible loss to forestry through an unintelligent application of the Land Reform policy, whereby all large landed estates are to be broken up, is drastically criticized. In

view of the wretched condition of most of the small private forests *vis-à-vis* those of the old feudal landlords, it would indeed be regrettable to see grand old forest estates broken up into unworkable small parcels. In view of Schenck's own figures, which show the State forests to be most highly productive, it is difficult to understand his argument against the transfer of large private forests to State management.

An extraordinary tenet is propounded that because the normal forest failed to provide for the abnormal needs of the Hitlerite war and post-war period, therefore the theory of sustained yield forestry is fallacious. Schenck recommends that as a safety factor a country should retain a huge extra reserve, like that of the U.S. National Parks, as stocks additional to the general sustained yield forests of its own bread-and-butter requirements. Would it not be better common sense to maintain the larger area, but to maintain the whole of it on a sustained yield basis?

Because the Halstenbek nurseries near Hamburg are inadequate to supply the plant requirements of the reafforestation programmes, the author foresees difficulty in fulfilling the task ahead. The German forest staffs, however, have not been slow to redesign their nursery policy, with numerous *Kamps* wherein seedlings are raised in immediate proximity to the forests.

Heavy post-war fellings, including the atrocious wastage of the 1945–6 fuelwood programmes, are blamed by implication on the Allies. The Chairman of the U.K. Forestry Commission is named for his 'preposterous' attitude in demanding German timber to ease Britain's immediate post-war famine. He is pictured as having nearly killed the goose that laid the golden eggs, every one of which should have been reserved for local consumption.

Looking into the future, Schenck cannot see German towns, railways, mines, and industries being rebuilt within a matter of generations, and then only at the cost of complete loss of all her forests. He does not offer one hint, however, that the people themselves might consider seriously, in a way they have never done before, matters of timber economy.

That the Germans and German foresters have a hard furrow to plough nobody will deny, but that is not a valid reason for segregating their forests from the rest of Europe and giving them preferential treatment.

'The salvation of Western Europe is closely interwoven with the salvation of German forests.' I agree; but would substitute the word *European* for the word *German*.

Woodland Crafts in Britain. By H. L. Edlin. B. T. Batsford, Ltd., London, 1949. 15*s*.

Review by G. C. Wolryche-Whitmore

IT is to be hoped that this book will be widely read, for it is in reality the history of forestry in Britain, set out in simple language, from ancient times when the land was densely covered with scrub and timber down to the present day.

The author reminds us that from early days to the time of the Industrial Revolution, when metal began to replace wood for many of our requirements, the whole community depended for its wants on timber from the forests. All such trades as tool making, wheel and mill wrighting, house and boat building, farm requirements, and many others, were completely dependent on the woodmen who lived in or near the forests, and on the raw material that they provided. We are not allowed to forget that even now everyone is still dependent to a very large extent on woodland products, and that, too, with a far greater consumption per head of the population than before.

Three chapters are devoted to describing the evolution of felling tools, haulage, and conversion. Fifteen chapters deal with the common timbers in use, in alphabetical order,

describing where they grow, their uses, method of conversion, and the various names under which they are known in different parts of the country. The remainder of the book deals with woodland carpentry, the work of mill and wheelwrights, house building in early days, charcoal burning, herbs, dyes, and other woodland products. The author's detailed description and about 150 excellent photographs enable the reader to see the different craftsmen at their various trades and to appreciate the truth of the old saying that necessity is indeed the mother of invention.

Spoon-fed as we are now by mass production for many of our needs, few people realize that timber worked only by hand supplied all the wants of the community to within the last 150 years, and that even in these days wood in some form or another is absolutely essential to man's existence.

As no single individual could possibly have an intimate acquaintance with all the processes described in this book, one must admire the lucid way in which the author has dealt with the subject. As he tells us, he has gathered his information largely from the craftsmen at first hand, and has been greatly assisted by the Rural Industries Bureau, the National Museum of Wales, and other sources. Most people will close the book with a feeling of regret that so many of these old industries and methods are dying out or have undergone great changes. Certainly the number of old men who appear in the photographs would indicate that the younger generation is not following their fathers' trade. But is it really surprising that the youth of the country should prefer to look for work in which some of the drudgery is avoided? The extreme case, perhaps, is that of pit sawing. Who could wish to perpetuate this method, or see a general return of timber hauling by horses, except for light work? The tractor, in various sizes, is incomparably superior to the old methods, which were hard on men and horses, especially on hilly ground and in bad weather.

Surely in these days of electricity and oil-power it should be possible to provide a life where a craftsman, working in country surroundings but assisted by the machine to eliminate the drudgery, can still produce goods for which skilled knowledge and craftsmanship are required?

The State forests on a large scale will be building up communities dependent on wood, and so, too, on a small scale will the private estate groups which it is hoped will gradually be formed throughout the country. Even now in some areas the local wheelwrights are becoming more and more dependent on the estate mills for such operations as sawing out shafts and felloes, &c., previously done by hand.

With wages at their present level there can be few trades which can produce goods at economic prices entirely by hand. Basket-making, sheep hurdles, and other under-wood trades may be the exception, though efficient cross-cutting and morticing machines would probably assist these trades also.

The produce of our forests is now a matter of prime urgency to the country, for the days of unlimited cheap imported timber are probably ended for many years. It is a constant matter of surprise to foresters at home and abroad that our daily, weekly, and local press, with very few exceptions, largely ignores the subject of forestry, and yet at all agricultural shows where woodland products are exhibited immense interest is taken in them by a very large number of persons. The public are in need of education in respect of country life. It has taken two world wars to make our people appreciate the value of home-grown food, and few realize as yet the part that our woodlands played in the first and second world war, and are to play in the future.

Mr. H. L. Edlin has rendered a valuable service to the country by his book, for which all foresters and others will be grateful.

The Propagation of Trees, Shrubs and Conifers. By WILFRID G. SHEAT. Macmillan, London. 25*s.*

Review by W. P. K. FINDLAY

THE subject of propagation is a controversial one, for methods that succeed under one man's hand in a certain locality may fail in another's elsewhere. It is, therefore, unlikely that any horticulturist will agree 100 per cent. with what is written by another on this subject.

Mr. Sheat describes fairly briefly the principal methods used for propagating plants, assuming that the reader already has a certain amount of horticultural knowledge. Then follows a comprehensive list in alphabetical order of all the trees and shrubs normally grown in this country, giving under each genus the methods recommended for propagating the various species. Where a plant can be propagated successfully by several methods, he lists these in order of practicability. The author concludes that at present no commercial advantage is gained by the use of growth-promoting substances for the establishment of cuttings.

There is no reference to the propagation of *Salix* spp. which is surprising in view of the widespread interest in growing the cricket-bat willow. If the author considers their propagation to be so simple as to be unworthy of description, this fact might usefully have been stated.

The book is written primarily from the point of view of the commercial horticulturist and is not intended for the professional forester. However, many foresters, especially on private estates, are responsible for the propagation and planting of ornamental trees and shrubberies, and for them this book should be a handy source of information. It brings together a great deal of useful knowledge that is not readily available in any other one volume published in this country.

The book is illustrated with a number of good line-drawings, showing methods of grafting, &c., and the production is up to the high standard one has come to expect from the publishers.

The Economic Problems of Forestry in the Appalachian Region. By WILLIAM A. DUERR. Harvard University Press; London: Geoffrey Cumberlege, 1949. pp. 308. 27*s.* 6*d.*

Review by J. J. MACGREGOR

THIS work appears in the well-known series of Harvard Economic Studies and represents a welcome addition to the rather limited number of publications on the economics of forestry. As the title implies, the study is based for convenience on the Appalachian Region—the five States of Kentucky, North Carolina, Tennessee, Virginia, and West Virginia—but the principles propounded have wider associations in forestry-resource management. As Chief of the Division of Forest Economics at the Southern Forest Experiment Station, New Orleans, and also as Chairman of the American Foresters' Committee on Scope and Research in the Economics of Forestry, the author is well qualified to write on his subject.

Some idea of the scope of the work is apparent from the chapter titles which follow the introductory pages on the field and character of forestry economics: Forestry Provinces of the Appalachian Region; Problems of the People and the Land; Problems of Forest-

land Management; Problems of Timber Management; Marketing Problems—introduction; general marketing problems; problems in marketing pulpwood and allied products, sawmilling products, and miscellaneous products (three separate chapters)—and Problems in the Consumption of Forest Products. An appendix includes definitions of forestry economics and the quantitative position of timber in the economy.

Among the author's aims are those of defining the field of forestry economics, and outlining the economic problems of forestry as a background for research and ultimately aiding in the solution of these problems by encouraging better understanding and more pointed research. These aspirations are set out in the opening paragraph of the preface, which goes on to explain the regional approach. There are many economic problems which are not covered, and indeed one cannot expect them to be covered, when marketing, for instance, has been given full attention.

In the introduction it is stated that the entire book serves as a definition of the economics of forestry. While it is thought best to let the definition unfold gradually, a summary of the content of forestry economics and some of its principal characteristics is given, to assist in the process.

Arguing from the general definition of economics the author concludes that forestry economics is the branch specially concerned with the allocation and application of forest resources, including productive factors and technology. Although the subject cannot properly be placed within rigid boundaries, the author takes pains to circumscribe the contents as far as possible, and to show that forestry economics has a co-ordinating function in evaluating the methods and results of the biologist and of the engineer, in terms of human satisfaction. A main theme of the book is that fuller use of the economic techniques can be made with advantage in forestry research. Another purpose is to show where these techniques can be used. It is stated that one aim is to demonstrate the usefulness of the 'economics approach' and the 'economics viewpoint' in forestry research: the approach is a system of research methods; the viewpoint is that of human welfare.

The author is thus led to place the emphasis on his analysis on social rather than private objectives, although the study of private enterprise is not neglected. This approach makes it inevitable that other segments of the national or regional economy should be considered, as forestry represents only one of the activities competing for scarce resources.

The field of study is divided into five main branches, each with two main subdivisions, as follows: I. Forest-land economics; (A) land use: (B) land institutions. II. Economics of forest production; (A) forest enterprise; (B) forest management. III. Economics of forest industry; (A) industrial organization and operation; (B) industrial processes. IV. Distribution and prices of forest products; (A) marketing; (B) prices. V. Economics of consumption of forest products; (A) demand; (B) use and requirements.

There is a most useful discussion on what might be termed the political economy of forestry. In determining what constitutes a problem, a distinction is made between those which can be defined objectively and subjectively. This depends on whether they concern things or people. Objective criteria are based on physical standards, but examples of subjective standards are spiritual and cultural values. The book, however, restricts itself to certain economic standards, in particular those affecting 'maximum total economic welfare' or what with certain qualifications is taken as 'real income'. Thus an economic problem is taken as a condition which results in a loss of real income which would be related to such things as some geographical area or national boundary and over an indefinite period of time beginning in the immediate future. It is made clear that the criterion for judging forest economic problems is maximum total income, not maximum income to forestry or to forest land, labour, or capital.

There is need for forestry activity to keep in step with the other industrial activities of the national economy, but in doing so the destruction of its recuperative powers must be avoided. However, to see forestry in proper perspective the author holds it is necessary to remember that it is only one economic activity. It is vital as a cog in the economic machine, and the importance of the little defects which it possesses should not be over-emphasized. In the light of these views the author outlines the problems or maladjustments within each of his main fields of study. This outline, while not intended to be exhaustive, emphasizes some items of regional importance. The list is too long to quote, but generally it can be said to cover problems associated with uneconomic allocation of factors of production, and inefficiencies arising from existing institutions, conventions, and programmes; unsuitable methods and a host of specific maladjustments not easily classified. The scale and significance of these problems are examined in the setting of the Appalachian regions. The descriptions, analyses, and a few maps represent a most useful and comprehensive study of the region, although information is lacking for the finer measurement of some of the features.

In line with the author's approach he begins with a study of the social and general economy of the region, and then goes on to deal with the many specific economic problems and practices of forestry, and gives rather a welcome prominence to marketing, which is partly treated on a commodity group basis.

Unlike most other American books on forest economics it offers much that is highly relevant to the study of British conditions. Here in the Appalachians we find the same situation of small-scale production, a large variety of sale products, the need for timber grading, and generally poorly organized and spasmodic marketing.

There is no doubt that the makers of forest policy in any country would benefit greatly from familiarity with just this kind of exhaustive and comprehensive analysis of the many and complex economic problems with which they have to grapple.

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NOTICES

The Use of Timber in Mining. By H. Henshaw, M.I.Min. E. Timber Development Association Ltd., 75 Cannon St., London, E.C.4.

THE author of this 'red booklet' and the Timber Development Association are to be congratulated on a summary of real value to foresters and others in Great Britain. The illustrations and the matter are very clear. Every producer of pit-props should look at the photographs on p. 71 of poor and good roof supports, and the strength data of *properly prepared* home-grown props, in comparison with imported props, on pp. 75 and 76. The average annual consumption of mining timber in Britain in 1945–7 was over 600,000 standards of 180 or 165 cu. ft.; and in the period 1942–7 about 16 per cent. of mining timber was imported, and 84 per cent. was home-grown. The author was for 12 years on roof-control research. There is a foreword by Prof. Statham of the Chair of Mining at Sheffield, and the author thanks the National Coal Board for permission to publish the work. Copies of the booklet are available free from the Timber Development Association to bona-fide applicants.

Journal of the South African Forestry Association, No. 17, February 1949.

THE number contains two items of special interest to British foresters dealing with the softwood saw-milling industry of South Africa and how it might be organized. The Board of Trade and Industries Report No. 304 is reviewed. The softwood saw-log output from the State plantations of *Pinus patula, radiata*, &c., has risen from 73,000 tons in 1939 to 324,000 in 1945, and is expected to be 380,000 by 1955. The corresponding figures for the private plantations in 1939 and 1945 are 38,000, and 198,000 tons. The State saw-mills numbered 4 in 1939 and 12 in 1945; the private mills 45 and 137, correspondingly. Twenty-five per cent. of the State mills but 83 per cent. of the private mills have a maximum capacity of only 7,000 tons per annum, the lowest output category, i.e. the State mills are larger on the average. The Board found that the profits of 5 of the private saw-millers were 18 per cent. in 1938 and of 11 of them were 75 per cent. in 1943; that the State mills were on the average less efficient than the good private ones but had done more to improve quality of output; that this last was the main argument for continuing them, supported by a real danger of dominance by one or two private groups if the State ceased to mill. The Board's report favoured divorcing the milling of softwoods from the growing of them by the State, and the creation of an ordinary share company to handle the milling, with the State holding a majority of the ordinary shares. (It remains for the Government to decide what action it will take on the report.)

The other very interesting and controversial item in the journal is an article by Mr. A. J. O'Connor on the above report entitled 'Sawmilling Policy in Relation to Timber Produced by the State'. He holds extremely strong views on the dangers to State and private growers of softwoods from 'middleman-sawmillers', as he describes those who mill but do not grow trees, if the latter are allowed to control the situation and dictate policy and prices to Government and the consumer. He is against the suggested State controlled milling company and in favour of the Forest Department's proposal for a Forestry Commission, with powers from Parliament and free of Public Service Commission control, Tender Board regulations, and other hampering restrictions. This Commission would include strong

growers' representation, would absorb the Forest Department, and would mill and sell the products, either direct or through existing distributing channels.

Without judging the local political issues, British foresters and saw-millers, State and private, may learn much of value from these rival arguments and their upshot in S. Africa, against the day when similar problems arise in Great Britain.

Empire Forestry Review. Vol. 27, Nos. 1 & 2 (1948); Vol. 28, Nos. 1, 2 & 3 (1949).

THIS journal is now publishing quarterly from Vol. 28, No. 1, of March 1949, and continues to set a very high standard in scope and value. The range includes excellent articles on temperate as well as tropical, and European as well as North American and Australasian forestry. The Association which publishes the journal and the journal itself need and deserve all possible support from foresters in Great Britain.

Unasylva.

THE Food and Agriculture Organization of the United Nations continues to publish its journal every two months, in English, French, and Spanish. It contains some excellent technical matter, whatever differences of opinion there may be on the more controversial economic activities it describes. Vol. II, No. 3, on Latin America, is particularly informative. Vol. III, No. 4, includes a paper presented to an international forestry conference at Mysore in March–April 1949 on 'Meeting Asia's Timber Needs'. In the opinion of competent critics that paper is unsound and misleading. It doubts the reality of the timber shortage in Asia and holds out exaggerated hopes of the possible savings in timber by standardization, prefabrication, and mass production. The series of 'Commodity Reports' on sawn softwood, pulp and paper, pit-props, railway sleepers, hardwoods, fibreboards, and plywood is a useful survey of world problems, with an inevitable proportion of unknown factors, such as Russian exports. EDITOR

Fire Control Notes, Vol. 9, No. 4, October 1948. Forest Service, U.S. Department of Agriculture, Washington.

BE it the lone hunter in Monongahela, W. Virginia, or the crowded picnic party attempting to boil a tea-kettle over a twig fire in the New Forest, the fire patrol can behave like a S.S. policeman or like a London bobby. One will make a soured foe of the wrongdoer; the other will stand a good chance of creating real forest-mindedness in the country-starved brains of his 'customers'. O. L. Lute Mullenax believes in making forest friends when on patrol.

Fred. G. Ames advocates simple de-bogging equipment for carrying on crawler tractors. A few feet of $\frac{3}{8}$ in. logging chain, a couple of hours' work by the village smithy, a stout 6-foot pole and it should be possible to get the tractor out of any normal bog hole if it has not been allowed to dig itself down too deeply.

Vol. 10, No. 2, April 1949.

THOUGH not required so much for fire protection in this country, Art Roberts's adaptation of the ordinary angle-dozer or bull-dozer for clearing areas of heavy lop-and-top is simple and should save enormously on our present costs of cleaning up war-felled areas for reafforestation.

J. A. Egan describes the Summerfield fire-line V-scraper for dragging behind an ordinary pick-up lorry. Obviously this could only be adopted on our easier and more level heathland forest areas, but I estimate that there would be change out of a £5 note to make it. For fire-tracing or fire-ride maintenance it should outstrip any tractor-drawn equipment.

Neither the extreme point nor the heel of an ordinary brushing hook serves much actual cutting value, but these are the portions of the blade which cause the greatest number of accidents. After full test, the Forest Service has now specified that their single-edge hooks be manufactured with completely blunt toes and heels.

Vol. 10, No. 3, July 1949.

MISSOURI Conservation Commission constructs fire towers up to 60 ft. high of wood. George O. White compares the cost of 2,200 dollars for these with about 4,000 dollars for steel towers of similar height. He gives no constructional details but some photographs.

Henry Sipe has a long article on law enforcement and its effect over a period of years in reducing fires on the Cumberland National Forest. I am not sure that he has not hit a bigger nail on the head when he says: 'When children are not taught things in school, they will grow into adults faster than forest education can reach them. If parents are unsympathetic, children are inclined to be likewise.' Parents and schoolteachers will be better fire prevention officers than magistrates and judges.

W. F. Biggerstaff describes portable radio equipment in some detail. We are behind in this. Even some of our police and full-time County Fire Services are not yet radio-equipped.

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Printed in Great Britain at the University Press, Oxford, by Charles Batey, Printer to the University